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EVALUATION OF "WITHIN VESSEL" SEWAGE SLUDGE COMPOSTING SYSTEMS IN EUROPE

by

Battelle Columbus Laboratories
Columbus, Ohio 43201

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16. ABSTRACT

This study was conducted as a cooperative effort by Battelle Laboratories in Frankfurt, Germany; Geneva, Switzerland; and Columbus, Ohio. The objectives were: (1) to update a review of the state of the art of sewage sludge composting in Europe; (2) to evaluate a European-designed, continuous, thermophilic, mechanical, aerobic, composting system in Germany; and (3) to compare its cost to those of the U. S. Department of Agriculture's Beltsville static-pile, aerated composting system. This report addresses the general characteristics of the European composting systems and a bioreactor in Hochheim am Main, West Germany.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Composting of municipal sludges in windrows and aerated piles has been shown to be a feasible sludge disposal alternative. Wastewater sludges have been composted on a regular schedule at Beltsville, Maryland, and Bangor, Maine. In this study, European within-vessel composting systems were evaluated. It is hoped that the information provided in this report will be of assistance to engineers concerned with the design of composting facilities.

Francis T. Mayo, Director
Municipal Environmental Research
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PREFACE

This report includes a survey of European within-vessel composting systems and a three-month on-site evaluation of one of the systems. During the on-site evaluation, mechanical difficulties were experienced-the reactor's compost extraction mechanism failed. There are indications that the failure was brought on by operation with an excessively wet charge. The manufacturer has indicated that continuing improvements are being made in the extraction mechanisms. This will no doubt make them less prone to failure caused by excursions from recommended operating conditions.

Clearly, the experimental results reported in this portion of the study may not be representative of this within-vessel composting system during mechanically trouble-free operaton. Nevertheless, the investigators' presentation contains much information of value to the designer and plant operator; consequently, it has been retained in the report. Of particular interest are the investigators' method of approach, and the insight they offer into the operation and economics of composting systems.

Recognizing recent interest in composting of sewage sludge in the United States, the Ultimate Disposal Section, MERL, U. S. EPA, is continuously evaluating both the unconfined and within-vessel composting of sewage sludge in the United States and abroad. Several studies (including a follow-up study on BAV reactors) are in progress. Interested persons may contact the project officer, Atal E. Eralp (513-684-7663), for further information.

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ABSTRACT

This study was conducted as a cooperative effort by Battelle Laboratories in Frankfurt, Germany; Geneva, Switzerland; and Columbus, Ohio. The objectives were: (1) to update a review of the state of the art of sewage sludge composting in Europe; and (2) to evaluate a European-designed, continuous, thermophilic, mechanical, aerobic, composting system in Germany, and to compare its costs to that of the U.S. Department of Agriculture's ARS, Beltsville, Maryland, static-pile, aerated composting system.

The results of this study showed that sewage sludge/bulking agent composting is well established in Europe and that the center of activity is in West Germany. At least 15 European systems were identified, and seven of these could be classified as "within vessels". The future of sludge composting in Europe is dependent on market economics and on continued public acceptance.

During the on-site evaluation at the selected plant, the vessel's extraction mechanism failed. The failure was attributed to agglomeration and compaction of the sludge/sawdust material in the bottom of the vessel. This failure has occurred at this plant four times in 1.5 years after start-up. It is possible that at this sewage treatment plant, a difficult-to-dewater-sludge may have been encountered.

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SECTION 1

INTRODUCTION

Composting is a well-established method of stabilizing organic wastes. It is used to convert leaves, grass, and wood trimmings into a usable soil product. In recent years, the Agricultural Research Service (A.R.S.)* of the U.S. Department of Agriculture, with the support of the U.S. Environmental Protection Agency, has developed a composting procedure for digested and raw sewage sludges. This process utilizes an open pile of sludge cake mixed with wood chips. Air is drawn down through the pile and into a vacuum system where the gases are eventually discharged through a stable pile of compost for odor control. The procedure is referred to as aerated-pile composting and works well with a minimum amount of capital investment. However, it requires considerable land and labor, and the process is conducted out of doors.

To overcome the problems associated with open air composting, several within-vessel, continuous composting processes have been developed and are in use in Europe. Some of the advantages which may be expected from these within vessel, continuous composting processes are minimum land and labor requirements, low maintenance schedules, and effective odor control.

To evaluate the status of European practices, a review study was conducted by Battelle's Columbus Laboratories under a contract from U.S. Environmental Protection Agency. The study had two main objectives: (1) identify the existing composting practices in Europe and compile information on operating modes, effectiveness, reliability, and costs; (2) obtain experimental data to verify the efficiency and the reliability of one commercial, within-vessel system. The results of the investigation are presented in this report.

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*A.R.S. has recently been renamed Science Education Administration (S.E.A.) of U.S.D.A.

SECTION 2

SUMMARY

Of the seven European countries surveyed for sewage sludge composting practice, West Germany is the center of activity with more than 30 operating plants. Sweden follows with 20 which are either in operation or in the planning and design stage; Switzerland has nine which are mostly the Bühler rotating drum process; France has five; the United Kingdom has one; and Italy and the Netherlands have none. These data are for systems where sewage sludge is the predominant waste component. If municipal solid waste intensive systems are also included, the number of installations would be higher. [References (1) and (2)].

The European composting processes identified in this study are classified into five categories: within vessel, windrow, rotating drum, pressed bricks, and fermentation cells. The processes described and evaluated according to category are listed in Table 1.

The feasibility of composting sewage sludge mixed with a bulking agent is now well established in Europe, but the future of general composting technology in Europe appears to depend on the market economics and continued public acceptance, rather than on technological improvements.

From Table 1, in the within vessel category, the Biologische Abfallverwertungsges, mbH & Company (BAV) process is the most common sewage sludge composting system in Europe. BAV has constructed at least 19 plants in West Germany and have at least 5 plants either in construction or design. Thus, based upon the popularity of this process, a plant using the BAV system was selected for detailed study as being somewhat indicative of European within vessel technology. After considering several options, the sewage sludge composting plant at the Hochheim am Main Wastewater treatment plant was studied in detail to obtain an indication of the efficiency and reliability of an operating plant. This plant is fairly typically sized for plants having installed within-vessel systems. Four other installations employing the BAV composting process were visited for one day, but limited time and funding prevented any extensive evaluations of these other plants.

There are, of course, limitations inherent in picking a single plant to reflect a population. In particular, when technology is changing rapidly as it is in the within-vessel field, there is a danger that problems uncovered in the study are unique to the installation studied, and not necessarily reflective of the entire population. While efforts can be made to minimize

TABLE 1. EUROPEAN SEWAGE SLUDGE COMPOSTING PROCESSES

Category	Process	Number of Operating Plants[b]
Within Vessel[a]	BAV	19
	Carel Fouché Languepin	1
	Roediger/Fermenttechnik	1
	Schnorr Valve Cell	2
	Societe General D'assainissement et de Distribution (SGDA)	1
	Triga	2
	Weiss	3
Windrow	BIO-Manure	2
	Hazemag	-
	PLM	-
Rotating Drum[a]	Bühler	9
	Dano	-
	HKS	2
Pressed Brick	Brikollare	2
Fermentation Cells	Prat	1

(a) These processes usually include a final windrow cure.

(b) Plant size ranges from 2 to 10 tonne of dry sludge per day.

NOTE: Addresses of the manufacturers contacted in the course of this study are listed in Appendix A.

this effect, effects can only be unequivocally resolved by studying a broader population.

Evaluation of the Hochheim am Main sewage sludge composting plant was based upon a two-month, on-site, detailed study in the following areas: (1) reliability of the plant's mechanical components; (2) process parameters which are influenced by the progress of the composting process, such as oxygen and carbon dioxide concentration in the exhaust gas, temperature rise and temperature profile within the vessel, and total retention time of the feed material; (3) measurement of the odors originating from the facility; (4) chemical and physical characterization of the feed material and the final product; and (5) cost information.

While Battelle-Frankfurt scientists were on-site to conduct the research, the bioreactor's product extraction mechanism failed. This equipment malfunction was attributed to the agglomeration of the composting material within the vessel. This equipment malfunction has occurred four times during the past 1-1/2 years since start-up. The manufacturer believes the reactor can be redesigned to avoid this problem and can point to a number of other installations with a more favorable operating history.

During the two-month evaluation period, the reactor produced a product whose chemical and physical composition did not differ significantly from the feed material; did not maintain a constant internal temperature; produced a non-uniform carbon dioxide off-gas profile; and emitted odors, during the product discharging cycle. These odors were detectable several hundred meters from the wastewater treatment plant. The exact cause for these results was not determined. But, it is probable that the product agglomeration was caused by the combined effect of high moisture in the feed at thermophilic conditions plus the lack of internal mixing in the vessel. The reader is cautioned, however, that these observations represent the experience at only one plant and that this plant may not have been properly operated or the wastewater may have had an unusually difficult treatment requirement. Resources available to the project were not sufficient to examine these questions. Furthermore, the Battelle-Frankfurt research staff did visit other BAV-type plants where the final product appeared more mature and odor-free, although no data could be developed within the scope of this study to verify these observations.

Based on data from the Hochheim plant, an economic evaluation was made and the BAV composting process was found to be capital intensive. The initial investment cost would be higher in the U.S. due to adaptation or redesign of European equipment specifications to U.S. equipment. The total annualized costs appear to be higher than the USDA's ARS aerated, static-pile composting process and such options as landfilling, landspreading, or trenching. This cost summation is based on annual processing cost; the income from possible sale of the compost is not included. Further investigation would be required before a direct comparison of the various processes/methods can be developed. The bioreactor capacity of most BAV installations is designed to serve a population of 30,000. The largest plant serves a population of 110,000 and uses two bioreactors, each processing approximately 350 m^3 of sludge cake per day. The use of larger capacity bioreactors to achieve further economic

benefits is thought to be limited due to the constraints on the reactor design. These physical constraints are (1) the maintenance of uniform air flow, (2) the removal of compost from the extremities of the vessel, and (3) the compaction of product at the base.

The above evaluation is based only on observations made at the Hochheim am Main plant. To develop a general assessment of within-vessel composting, at least one additional BAV plant and another process should be investigated. A good choice for a second process appears to be that offered by Triga because its design may offer a reduced possibility for encountering the aforementioned extraction problem. An experimental verification of this observation was, however, beyond the scope of this study.

SECTION 3

STUDY OF EUROPEAN SEWAGE SLUDGE COMPOSTING SYSTEMS

The primary intention of this section is to report representative and reliable information of the status of mechanical composting processes in Europe. Since the technology is relatively new and is evolving rapidly, a variety of sources for information, in addition to the literature, were required. Information was obtained through discussions with composting process inventors, license holders, plant manufacturers and plant operators. Representatives from Ministries on Environmental Affairs from France, Germany, Italy, The Netherlands, United Kingdom, Sweden and Switzerland were interviewed to obtain current data on sewage sludge composting. In addition, site visits by Battelle-Geneva, Battelle-Frankfurt, and Battelle-Columbus scientists to selected operating plants were made. These were the Triga plant in Royan, France; Bühler plants in Pfamensthal and Biel, Switzerland, and Leicester, England; and the BAV plants in Hochheim, Kronberg, Ferndorfthal and Rosbach, Germany.

Eleven different sewage sludge composting processes are described and classified according to type of process such as windrow, "within vessel", rotating drum, pressed bricks and fermentation cells. These processes are then rated according to five categories such as temperature control, air distribution, residence time, homogenicity of recycle and mechanical reliability.

The locations of each sewage sludge composting plant are listed by country and town in this section.

STATE OF THE ART OF SLUDGE COMPOSTING PROCESSES

Current Geographical and National Trends

France--

In 1977 about 12 million metric tonne (t) of MSW, 600,000 t of dry matter from community sludges and 1,600,000 t of dry matter from industrial sludges were generated in France. Seven hundred-twenty-five thousand metric tonne of MSW were processed in 92 plants (3) (47 windrow and 45 within vessel plants) to produce 380,000 t of compost. The development of sludge composting in France is recent (1975); however, by the beginning of 1978, there were 5 plants processing sludge and one under construction (see Table 2).

TABLE 2. SLUDGE COMPOSTING PLANTS IN FRANCE

Location	Name of Company	Process	Type of Wastes	Status
Salon de Provence	SGAD	BAV/SGAD	Sludge + MSW	Operating
Nantes-South	EPAP	BAV	Sludge + sawdust	Operating
Montargis	Triga	Triga	Sludge + MSW	Operating intermittently. R&D in an existing MSW composting plant
Dreux	Triga	Triga	Sludge + MSW	Operating
St-Palais-sur-mer (Royan)	Triga	Triga	Sludge + Sawdust + bark	Operating
Montbéliard	Carel Fouché Languepin	Carel Fouché Languepin	Sludge + MSW	Operating
Martigues	Sofitom	Brikollare	Sludge + MSW	Under construction, start-up scheduled for 1979

In France, compost is considered an organic soil conditioner and its main competitor is cattle manure. The market is not very large and the average selling prices for municipal solid waste (MSW) plus sewage sludge compost ranged from 5 to 35 FF/dt in 1977 ($1.10 to $7.70) which is not enough to finance the operating costs and amortization. On June 9, 1977, the "French Committee for the saving of raw material" made the decision to intensify and to coordinate the marketing of organic wastes as soil conditioners and to encourage fertilizer manufacturers to use the wastes as organic sources in their production. The policy is to improve the quality of the compost and try to obtain a selling price of 20 to 25 FF/dt ($4.40 to $5.50). Triga sells some of its sewage sludge mixed with bark compost from St Palais to a fertilizer manufacturer at a price of 120 FF/t ($27/t). From that point of view, sludge plus bark compost is better than municipal solid waste (MSW) plus sludge compost.

Germany--

The amount of sewage sludge produced, as a result of improved sewage and effluent treatment, is given in the 1975 Waste Management Program of the German Federal Government as 50 million m^3 of sludge from municipal treatment plants and 30 million m^3 of sludge from industrial treatment plants. Each sludge has a water content of 95 percent (4). The values correspond to 4 million t dry mass of sludge.

From data originating from an inquiry undertaken by the Abwassertechnischen Vereinigung (Technical Association for Waste Water), the Umweltbundesamt (Federal Environment Agency) has estimated total sludge dry weight at approximately 1.7 million t at the end of 1974, which corresponds to about 34 million m^3 of sewage sludge with a 95 percent water content (3). From this survey, disposal and recovery processes for sewage sludge such as incineration, composting, tipping (landfill), agricultural exploitation, selective tipping of agricultural utilization, and other disposal methods (tipping at sea) were evaluated.

This report concludes that in treatment plants with fewer than 20,000 inhabitants, agricultural application prevails, while in treatment plants with more than 20,000 inhabitants, the sewage sludge is primarily tipped. An overview of the quantitites of sludge taken from the survey mentioned above, and of the respective form of disposal, is shown in Table 3.

Windrow composting with additives--Composting sewage sludge in windrows without additives (sawdust, straw, bark) is no longer carried out in Germany although numerous attempts were made from 1930 until the present. Sewage sludge, without additives, has both low porosity and a high water content. These two factors, when combined, reduce natural aeration and favor anaerobic digestion to proceed. Strong, objectional odors develop during anaerobic digestion. Due to these strong, objectional odors which develop, composting sewage sludge without additives has been abandoned.

TABLE 3. SEWAGE SLUDGE PRODUCTION IN THE FEDERAL REPUBLIC OF GERMANY[4]

Size group (Number of inhabitants)	Population	Total sewage sludge, tonnes dry weight per year=100%	Incineration, tonnes dry weight per year	Composting, tonnes dry weight per year	Tipping, tonnes dry weight per year	Agricultural utilisation, tonnes dry weight per y.	Tipping or agric. utilisation, tonnes dry weight per year	Other processes, tonnes dry weight per year
2,000	31,230	2,200			501 (23)	1,272 (58)	427 (19)	
2,000 - 5,000	115,023	4,754			1,057 (22)	2,963 (62)	734 (15)	
5,000 - 10,000	322,022	16,254			1,480 (9)	9,128 (56)	5,646 (35)	
10,000 - 20,000	1,205,241	42,781	733 (2)	1,108 (3)	13,359 (31)	20,859 (49)	5,821 (14)	901 (2)
20,000 - 50,000	2,073,530	100,347	3,243 (3)		33,338 (33)	32,569 (32)	23,628 (24)	7,567 (8)
50,000 - 100,000	3,017,323	114,991	8,567 (7)	8,190 (7)	45,323 (39)	29,824 (26)	19,488 (17)	3,599 (3)
100,000 excluding city states	9,146,111	278,220	31,933 (11)		147,755 (53)	68,726 (25)	14,259 (5)	15,547 (6)
Total	15,910,490	559,547 (100)	44,476 (8)	9,298 (1.7)	242,814 (43)	165,341 (30)	70,002 (13)	27,614 (5)
		Tonnes dry-weight per year (in tonnes)						
Extrapolated to 100% of connected inhabitants = 48 million	48 million	1,678,640	133,428	27,894	728,442	496,000	210,000	82,840
		Amount of sludge corresponding to 5% dry-weight, in m^3						
	48 million	33,572,800	2,668,560	557,880	14,568,840	9,920,000	4,200,000	1,656,800

Sewage sludge composting plants--During the past 5 years, about 30 plants for the composting of sewage sludge have been built or are under construction in Germany (Table 4). These plants are capable of serving a cumulative population of 800,000. In most cases, the composting involves the addition of bulking materials such as sawdust. A research program is being conducted by the German Umweltbundesamt to determine whether these processes produce a pasteurized and pathogen-parasite-free product. Preliminary results of this research, as yet unpublished, may show that in some cases pasteurization is incomplete and that some final composted products may contain both human and plant pathogens.

MSW composting plants--In 12 of the 19 existing plants in the Federal Republic of Germany, the sludge is composted together with MSW (1). Considering both sludge and sludge/MSW composting, it is estimated that in 1977 the total amount of composted sewage sludge was only 3 percent of the total sludge produced.

Italy--

There are very few sewage treatment plant in Italy, and sewage sludge composting is limited to the research level. One project, at the University of Pisa, under the direction of Professor de Bertoldi, is sponsored by the Italian Research Agency (CNR). However, as of 1978, there are 28 plants that compost MSW. Twenty-one of these plants combine composting with incineration. Approximately 3,600 tons of MSW are processed each day by the compost/incineration method.

Two of these processes [Vöest Alpine and Renova (7)] could compost sewage sludge if mixed with MSW. Daniele Ecologica, S.p.A. is a licensee of Vöest Alpine, and the Novater company has the exclusive license in Italy for the Renova process. Portland Zementwerke of Heidelberg, Germany, operates a Renova MSW/sewage sludge composting process in Blauberen, Germany.

The Netherlands (Holland)--

No sludge composting plants were found in the Netherlands. MSW has been composted since 1929, using the Van Maanen (VAM) windrow process. The MSW from 110 communities is transported by train to two plants in Wijster and Mierlo. The unground refuse is digested in open piles, 6 m high, for 120 to 180 days. The piles are aerated occasionally by turning with grab cranes. The product is screened and ground to different sizes (35 mm, 15 mm, 6 mm) according to the end use. There are two Dano plants in Rijenhout and Soest.

United Kingdom--

As of 1978, there is only one operating plant composting sewage sludge located at Wanlip, near Leicester (8). About 10 to 15 years ago, MSW composting in Dano rotating drums was common; however, most of these plants have been shut down. In 1974, the Wanlip plant was reopened and processes 1000 t of MSW mixed with 500 t of digested sewage sludge (5 percent solids) each week. The product, packaged under the brand-name "Lescost", is marketed with some success.

TABLE 4. LOCATION OF SEWAGE SLUDGE COMPOSTING PLANTS IN WEST GERMANY

Process	Producer	Plants
BAV	BAV Biologische Abvallverwertungs Gesellschaft mbH & Co Berliner Strasse 22 6369 Schöneck 1 Tel: 06187/5004	Lambsheim Winterberg Weilheim (Teck) Gärtringen Delbrück Lübeck-Herrenwyk Hochheim (Main) Lollar Oberes Ferndorftal/Hilchenbach Steinenbronn Raisdorf Kronberg (Taunus) Wilnsdorf Schefflenz Eddersheim Rosbach v.d.H. Kandel Buchen Brilon-Messinghausen under construction: Vlotho Höhr-Grenzhausen Freigericht Waldenbuch Schlüchtern
Weiss	Gebrüder Weiss KG Maschinebau Abt. Umwelttechnik Kupferwerkstrasse 6343 Frohnhausen/Dillkreis Tel: 2771/5066	Deidesheim Dettenhausen Bad Liebenzell
Schnorr (Valve Cell Method)	Fa. Dambach Industrieanlagen GmbH Abt. Klärtechnik Postfach 1240 Adolf-Dambach-Strasse Tel: 07225/1841	Denkendorf Rastatt under construction Gaggenau
Method of the firms Roediger/Fermenttechnik	Fa. Wilhelm Roediger Industriehafen 6450 Hanau/Main	Mittleres Wutachtal
HKS-Method	Fa. IBP International Büro für Projektentwick-lung B.V. Heerlien Niederlassung Aachen Monheimsalle 51 5100 Aachen Tel: 0241/30505	Aachen (pilot plant)

A review of two recent summary reports (9,10) on sewage sludge disposal practices barely mentioned composting. However, underlying the apparent instability and dissatisfaction with existing land and sea disposal methods, there are some indications that composting could receive greater attention, especially if an economically proven process were available.

In particular, there appears to be an increasing interest in organic farming. There is also concern that plant and human pathogens and parasites can survive current land application and land filling sludge disposal practice.

Sweden--

In 1975, the Swedish parliament passed a resolution whose objective emphasizes recycling through better solid waste management. With this resolution, 20 Swedish communities or regions are planning, or are in the process of constructing, composting plants. At present, less than 1 percent of the total MSW and sewage sludge produced is recycled by a composting technique. According to recent estimates by the Swedish National Protection Board (SNPB), in the next two years approximately 7 percent of the total MSW and sewage sludge produced will be recycled by composting methods.

The SNPB has been engaged in research on composting MSW mixed with dewatered sewage sludge (11). The procedure was very similar to the ARS process. This study is reviewed below.

Forced aeration pile composting study--The undigested mixture was placed on a concrete tile, producing a set of parallel U-Channels for forced aeration. The parameters studied were the means and intensity of aeration, distance between the channels, degree of size reduction of the refuse, height of the compost heaps and influence of the climate over a year.

Compared to traditional composting systems, the one examined has no reactor for starting the process and no windrows for maturation. Instead, the degradation occurs in large flat heaps. It is believed that this will reduce the total cost and produce operating advantages.

The experiments have shown that this system may be used in a Nordic climate even if the water content of the starting compost is 60 percent or more. Due to the evaporation of moisture by the forced aeration, the water content decreases to the point where the composting process stops. Adding water to the composting piles is a necessary step to keep the composting process active. It is also essential to turn the pile at least once during the reaction period. This turning insures that the final product will be homogeneous.

It is also important to change the aeration flow direction between suction and injection. In periods with injection, the aeration rate must be increased in order to maintain the CO_2 content below 5-6 volume percent (vol %) (12). After 100 days, the material is stabilized, independent of

the size reduction of the refuse such that it can be piled without further aeration. A better result is achieved when the distance between the channels is reduced from 2.0 to 1.5 m. From the temperature point of view, it is better if the windrows are 3 m high rather than 2 m.

Switzerland--

The following information was abstracted from a recent research program conducted by Battelle Geneva Laboratories. The purpose of this research program was to evaluate solid waste disposal methods in Switzerland. Currently there are 9 composting plants in Switzerland, the latest of which went into operation in 1975 in Biel (13). All but one, in Uzeil, mix MSW with sewage sludge (see Table 5). In most cases, incineration and composting equipment are built side by side. The composting operation is used to dispose of sewage sludge. The incinerator burns most of the municipal waste and the rejects from the composting installation. Except for Biel, where a Dano installation runs in parallel with a Brikollare installation, all the plants use the Dano system for composting. The auxiliary mechanical machinery, such as hammermills, conveyors and screens, is usually produced by Büehler. A breakdown of the MSW flow in Switzerland is given in Figure 1 (13).

The construction of composting plants has practically stopped. Apparently most operating plants have difficulties in marketing the compost at a satisfactory price. Alternatives for the disposal of sewage sludge are incineration or direct sales to farmers (sometimes with prior pasteurization), but these also pose specific problems. The presence of heavy metals and glass particles is the most common objection to the use of refuse-derived compost. It may well be, however, that careful operation of the plant and better marketing could improve sales of the compost (see example of Leicestershire, Great Britain). It appears very unlikely that a number of combined MSW/sewage sludge composting plants will be built in the near future. One of the reasons is that the rejects of composting must be burned (landfilling is, for reasons of space, not feasible in Switzerland), therefore, an incinerator is necessary in any case. Building a larger incinerator instead of a combined system, generating only ash to be disposed, seems in many cases the simpler solution. However, the better-quality product from sewage sludge/sawdust only, might find better product acceptance in Europe.

Presentation of Sewage Sludge Composting Processes

Triga Process--

The Triga "Hygienisator" is an enclosed concrete, cylindrical tower, approximately 5 m in diameter and 8 m high, and is divided into 4 independent compartments. With this design, the tower contains 4 individual, independent reactors. Each compartment, or reactor, has its independent aeration, temperature and carbon dioxide measuring systems, but each compartment shares the common screw extraction mechanism designed for both product removal and subsequent product recycle. The screw extractor, located externally at the tower's base, rotates axially and travels on a track around the tower's circumference. Its movement around the circumference can be controlled either manually or automatically. Figure 2 is a diagram of the Triga composting reactor.

TABLE 5. SLUDGE COMPOSTING PLANTS IN SWITZERLAND

Location	Company	Process	Type of wastes	Status
Horgen	Buehler	Dano	MSW + sludge	Operating
Mannedorf/Pfannenstiel	Buehler	Dano	MSW + sludge	Operating
Biel	Buehler	Dano, Brikollare	MSW + sludge	Operating
Krauchthal/Worblental		Dano	MSW + sludge	Operating
Olten	Buehler	Dano	MSW + sludge	Operating
Beringen/Schaffhausen	Buehler	Dano	MSW + sludge	Operating
Penthaz		Dano	MSW + sludge	Operating
Genève/Villette		Dano	MSW + sludge	Operating

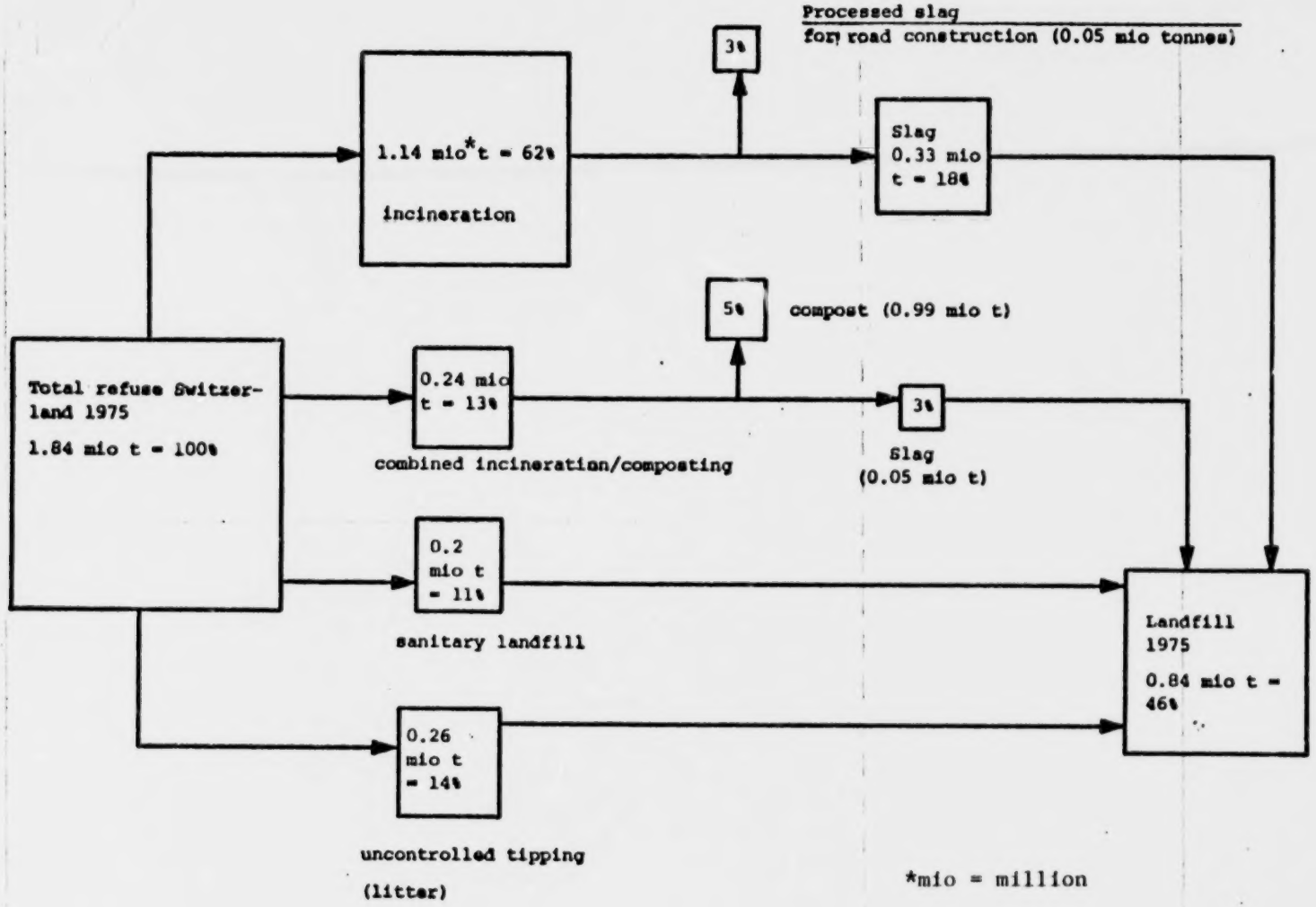
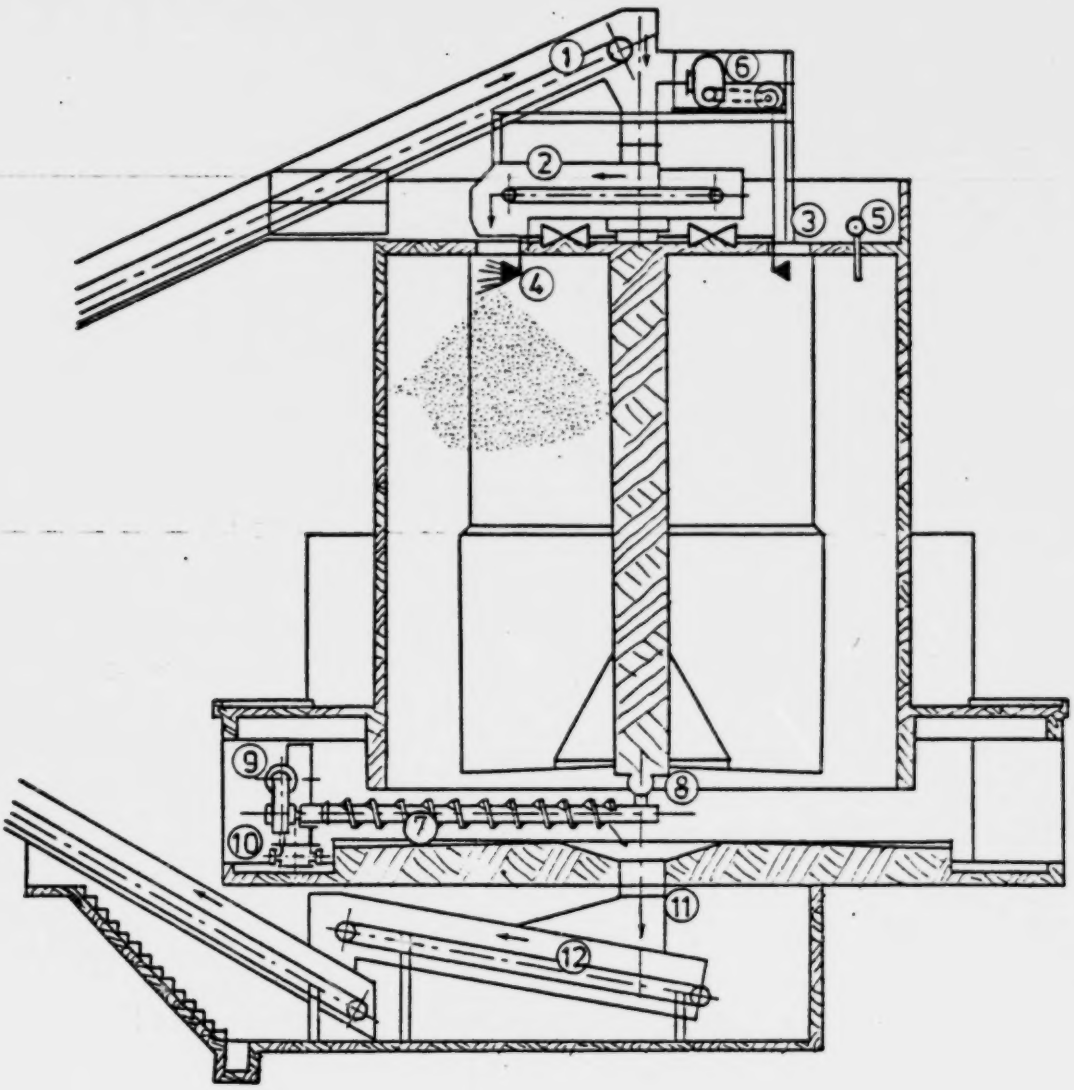


Figure 1. Refuse flow of Switzerland 1975 (13).



1 - 2 - 12 belt conveyors
3 feed port
4 water spraying nozzles
5 temperature probe
6 aerator
7 screw extractor
8 axis
9 trolley
10 rolling path
11 finish product exit port
12 finish product conveyor

Figure 2. Triga composting reactor.

The feed, raw dewatered sewage sludge plus bulking agent mixture, is blended in a horizontal mixing trough (Pug mill). The mixture is blended continuously within the trough by means of a double-shaft-with-paddles screw. From the mixing trough, the feed is conveyed to the top of the tower on a belt conveyor. One compartment of the tower is filled completely and is processed as a single batch. Fermentation is started by pulling air through the compartment's open bottom by a vacuum pump located at the compartment's top. The air flow rate is adjusted according to the temperature in the bed. At the start of the 8 to 10 day composting period, the air flow through the bed is adjusted to maintain the bed temperature at 70-80°C while maintaining a >10 percent oxygen concentration in the exhaust gas. The bed moisture is maintained at 50 percent and can be adjusted, if needed, with water spray nozzles located within each compartment. Bed depth is typically 7 m.

Additional product aeration and bed loosening is accomplished by daily extractions of the bottom fourth of the bed of each compartment with a screw extractor. The extracted bed is recycled using the belt conveyor system. Thus, by this method, product compaction at the bottom of the bed is minimized. The entire bed is removed after the active fermentation period and placed in a static windrow for a two-month curing period.

Triga plants--At the beginning of 1978, two raw sewage sludge/bulking agent plants were in operation in France, although plants based on MSW have been in operation for about 10 years.

Dreux plant--Originally, this was a MSW composting plant, but it was modified in September 1977, for the combined composting of MSW and sludge. The capacity of this plant is 60 t/d, MSW as received and 10 t/d, sludge. The sludge, flocculated with lime and ferric chloride, is dewatered to 80 percent moisture by a band filter ("Press Deg"). An analysis of the compost is given in Table 6.

St. Palais Plant (near Royan)--This plant was designed to compost the sewage sludge of the city of Royan (4,100 dt/yr) and began operation in July 1977. The sludge is flocculated with a polyelectrolyte and dewatered by a band filter ("Press Deg"). The bulking agent is sawdust and/or bark which account for 1/3 by weight of the feed. Initially, the plant used the pulp of grapes as the bulking agent but this was abandoned due to price. The residence time in the reactor, based on the original volume of the mixture of sludge cake and sawdust (or bark), is 10 days. During this time, the mixture is recycled 3 to 5 times. The curing time varies from 2 to 2.5 months. The production capacity is about 4,000 t/yr. An analysis of the cured compost is given in Table 6. Since the composition of the starting mixture was not reported, a comparison between feed and final product cannot be made. The investment for this plant was 2 million FF (~$400,000), of which about 75 percent is associated with equipment purchase. The two major components of the operating costs are: power consumption 40 kWh/t of sludge, and labor -- one man operates the plant. Appendix B describes some details of the Triga system and studies thereof.

TABLE 6. ANALYSIS OF THE TRIGA COMPOST
(Analysis: C.D.L.P. Melun)

Plant		Dreux		Saint Palais	
Mixture		sludge/MSW		sludge/pine sawdust	
Curing period		1.5 months		1.5 months	
pH		7.8		8.2	
C/N ratio		21.8		32.9	
Analysis by weight		dry basis	raw product	dry basis	raw product
Moisture	%		41		54.25
Organic matter	%	49.2	29	84.3	38.55
Mineral matter	%	50.8	30	15.7	7.2
Carbon	%	22.5	13.3	40.6	18.6
Cellulose	%	8.7	5.1		
Total Kjeldahl N	%	10.3	6.1	12.3	5.6
Total phosphorus (P_2O_5)	%	5.8	3.4	9.3	4.2
Total potassium (K_2O)	%	2	1.2	2	0.9
Total calcium (CaO)	%	37.3	22	36.4	16.6
Total magnesium MgO	%	4.2	2.5	1.3	0.6
Total S	%	4.7	2.8	6.3	2.9
Total Fe	ppm	7009	4135	3294	1507
Total Mn	ppm	792	467	104	47
Total Cu	ppm	294	173	203	93
Total Zn	ppm	1129	666	532	243
Total B	ppm	14	8	13	6
Total Cr	ppm	33	19	9	4
Total Cd	ppm	5	3	3	1
Total Ni	ppm	22	13	10	4
Total Pb	ppm	366	216	61	28

Carel Fouché Languepin Process--

The Carel Fouché Languepin (CFL) Company has been building composting plants since 1965.

Fermentation takes place in cells arranged in blocks comprising five levels. A vertical set of five cells represents one fermentation unit (or digester). Two blowers per digester can inject or draw air from each of the five cells fitted with air distribution ducts. The top cell is charged with the freshly pulverized MSW. Sludge can be added to the MSW before feeding. The fermentation mass passes vertically down the digester in five steps, and connection between cells is achieved by tilting floor gratings. The residence time in the digester is approximately a week. The only CFL plant which processes MSW and sludge is the Montbéliard plant which has been in operation since mid-1977.

The daily capacity is 150 t/d (as received) of MSW and 5 t/d of sludge with a water content of 80 to 85 percent.

Development of a new digester--CFL is just beginning a research program aimed at the development of a new digester for the fermentation of sludge. This research is sponsored by the French Environmental Ministry. The pilot digester will process 1 m^3/d of sludge mixed with carbonaceous source and/or minerals and/or polystyrene spheres. The aim of this research is to obtain a product similar to a peat because the French importation of peat is expensive.

SGAD Process--

In 1975, the "Société générale d'assainissement et de distribution" (SGAD) built a plant in Salon de Provence under the BAV license to process sewage sludge and municipal solid wastes. They had problems with the extraction screw conveyor and modified this system. Now, they have their own process which, in fact, is a "BAV modified" process. They have not built any other plants in recent years.

Salon de Provence plant--SGAD operates this plant which processes the municipal solid wastes and digested sludge for the population-equivalent of 60,000.

The MSW is ground and screened. The larger-sized fraction is burned in a rotary kiln and the smaller-sized fraction is sent for fermentation. The smaller-sized fraction is mixed with digested sludge which has a water content of 94 percent. This mixture is then fed into two reactors, 300 m^3 each. To equalize the flow rate between the mixers and the reactors, there is a short-term storage bunker. The temperatures at different locations and the CO_2 content of the exhaust gases are measured and recorded. The residence time in the reactor is about 15 days. The mixture is then extracted and formed into 2 m high curing piles. The curing time is approximately 10 weeks, without any further turning.

Dano Process--

The Dano process is probably the most widely used MSW composting system in the world. Approximately 180 units have been installed since the late 1930's. Some of the older units have been retrofitted to process sewage sludges with the MSW.

The key piece of equipment is a rotating drum about 25 m long and 3.5 m in diameter, equipped with knives in the interior which are designed to shred the material. Ventilators aerate the drum with the exhaust being forced into an underground earth filter outside the building. The input refuse is sometimes treated first in a hammermill. The output is screened, either by a separate vibrating screen or, in new plants, in the perforated end section of the drum. The final product is usually stored in windrows for further curing and screened prior to selling (see Figure 3, diagram of refuse/sewage sludge installation).

Typical operating conditions are the following: one Dano drum will process about 130 t/d as-received, refuse plus sewage sludge. Larger capacities are treated by parallel units. Normal municipal refuse and sewage sludge are mixed at a ratio so that the desired humidity is attained. e.g.:

- 100 t refuse + 30 t liquid sewage sludge, or
- 60 t refuse + 60 t sludge cake.

The residence time in the drum is 24 hours, but some units will maintain a residence time of up to 4 days, thus a more thorough decompostion is achieved. The internal temperature cannot be directly measured, but 50° to 60°C is the normal operating range, depending upon the operating conditions. Ten percent of the feed is lost as carbon dioxide and water vapor in the exhaust gas. The tumbling action of the drum not only provides a suitable environment for biological activity, but also reduces the refuse particle size through the shearing action of the internally positioned knives.

The output is about 8 percent metal (separated before or after the drum), 60 percent compost, and 30 percent rejects. The ratio of rejects to compost is, of course, dependent on the mesh of the screen.

The compost is nearly always stored in windrows and Dano claims that further aeration is not necessary. The storage time may vary from a few days to several months, longer periods giving better quality compost and allowing for seasonal changes in demand. According to Dano, 8 days of windrow storage is required by the German state authorities in order to eliminate any health hazard.

For the standard size Dano plant, 130 t/d, capital costs are about $1 million for the drum, machinery, electrical equipment, erection and start up, and about $0.5 million for the necessary civil engineering.

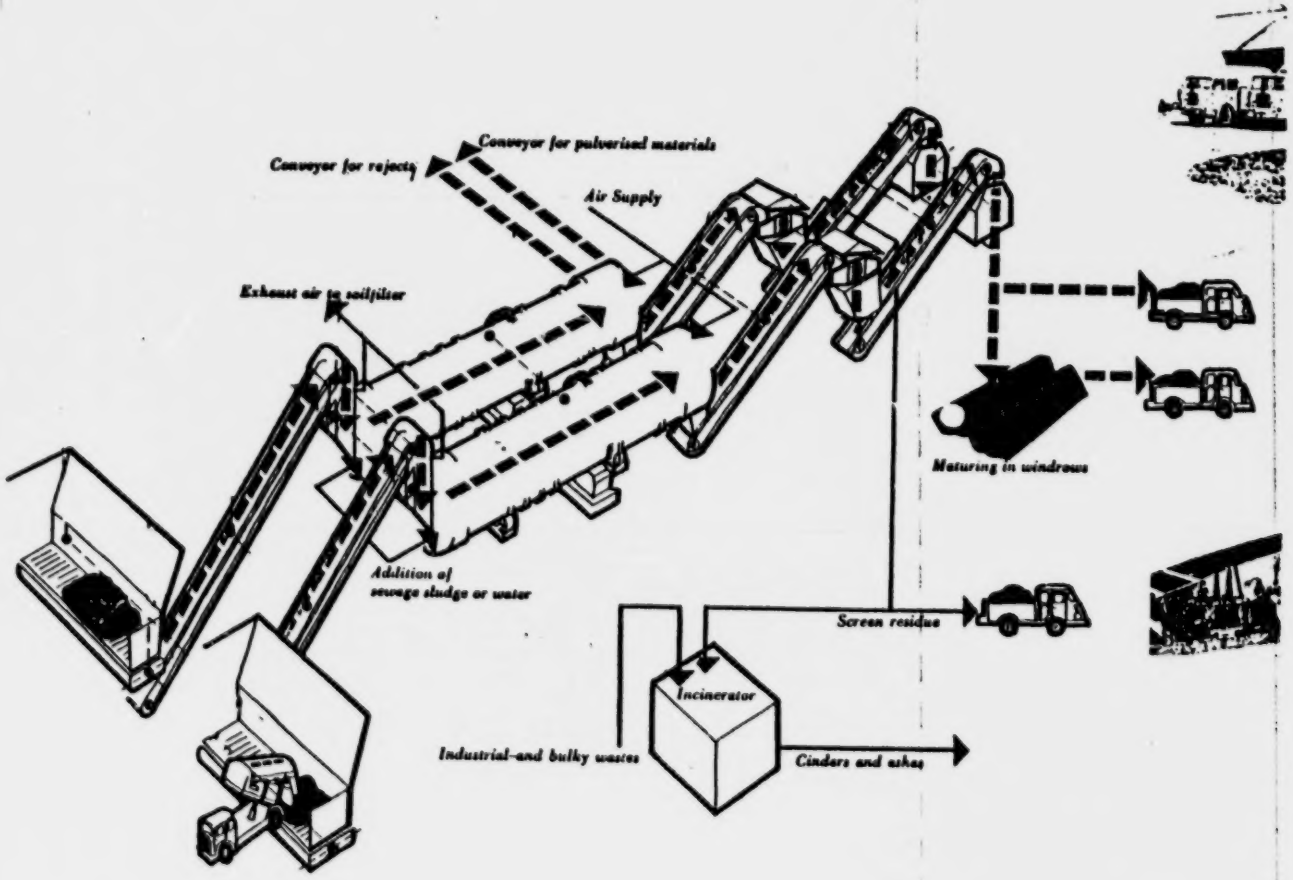


Figure 3. Schematic of Dano refuse composting plant.

The results of the compost analysis performed by the federal authority, Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG), at the composting plant of Schaffhausen (Beringen) are shown in Table 7.

TABLE 7. ANALYSIS OF DANO COMPOST AT SCHAFFHAUSEN, SWITZERLAND

Source: Swiss Federal Institute for Water Resources and Water Pollution Control Board

Analysis wt %	Compost Age, month		
	2	5	8
H_2O	46.1	43.2	51.0
Organic matter (dry)	40.7	38.3	35.6
N	1.0	1.0	0.9
P_2O_5	0.5	0.36	0.2
K_2O	0.7	0.5	0.4
CaO	3.7	5.9	4.6
MgO	1.3	1.5	0.9

Dano considers the Swiss Market to be saturated and is concentrating its efforts on southern countries such as Italy and South America. While most Swiss plants were built in cooperation with Bühler, a major manufacturer of solid transportation systems, screens and hammermills, Dano tends to operate more independently in its ventures abroad. Their new concept is a greatly simplified process with much less investment cost. They propose using the Dano drum as shredder compactor without any prior milling of the input refuse. The output is to be screened and used for landfilling. They claim that this is an economical solution to dispose of ordinary refuse and sewage sludge for communities of about 20,000 inhabitants. The refuse is claimed to be highly compacted, and the compost generated would be used only to cover and recultivate the landfilling site.

Bühler Process--

This process is similar to the Dano; in fact, the Dano rotating drum is a mixing component for blending the raw refuse with dewatered and liquid sludge. After blending, the mixture is placed in a roofed shed for further windrow composting. After windrow composting, the product is further screened and set aside for post-maturation prior to sale. Figure 4 represents the flow of materials in the Bühler process.

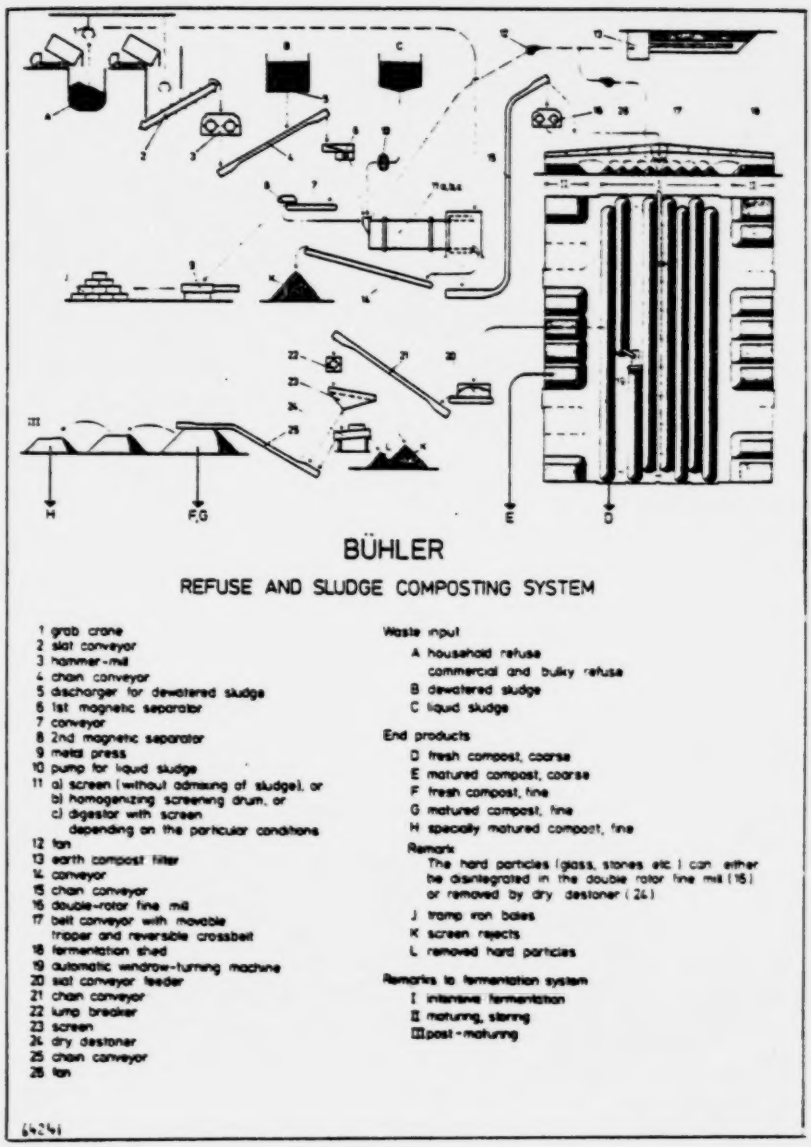


Figure 4. Bühler refuse and sludge composting system.

Brikollare Process--

The Brikollare process is a composting process offered by Industrie-Werke Karlsruhe Ausburg AG (IWKA) in Karlsruhe, West Germany. Two plants are operational, one in Schweinfurt, West Germany, the other one in Biel, Switzerland, where it runs in parallel with a Dano installation. A third plant is being constructed in Martigues, Southern France.

Strictly speaking, it is not a "within vessel" composting process. The screened refuse is mixed with dewatered, digested sewage sludge and pressed into bricks of 60 x 20 x approximately 15 cm size. These bricks are stacked and stored in an open shed where the biological activity lets the temperature rise to 70°C. After 2 to 3 weeks, the biological activity ceases because the bricks have dried out to 20-25 percent H_2O. At this stage, the bricks may be stored in the open for any length of time. As required, the dry bricks are milled and screened to ready compost. IWKA claims no further windrow storage is necessary (see schematic diagram and mass balance, Figures 5 and 6).

For 7-hour operation, 240 days per year, IWKA claims a capacity of 25,000 t/yr refuse (35% H_2O) and 8,000 t/yr sewage sludge (75% H_2O) which is equivalent to a population of 100,000. This input yields the following materials:

- 13,000 t/yr compost (25% H_2O)
- 8,500 t/yr rejects that must be disposed (25% H_2O)
- 12,000 t/yr of water evaporated during the fermentation of the brick and reduction of organic substances.

A turnkey installation including buildings, without sewage sludge concentrator, scrap metal and rejects presses will cost about 7.5 million DM* ($3.75 M) (1976 costs).

- Required operating personnel: 6 men
- Operating costs per tonne refuse or concentrated sludge: 25 DM ($12.50)
- Equivalent to an investment of 75 DM ($37.50) and annual operating costs of 8 DM ($4.00) per inhabitant.

All of these figures are given by the manufacturer, IWKA.

A particular feature claim for this process is the utilization of proven mechanical components that should not pose any particular operational

*DM = Deutsche Mark ($0.50)

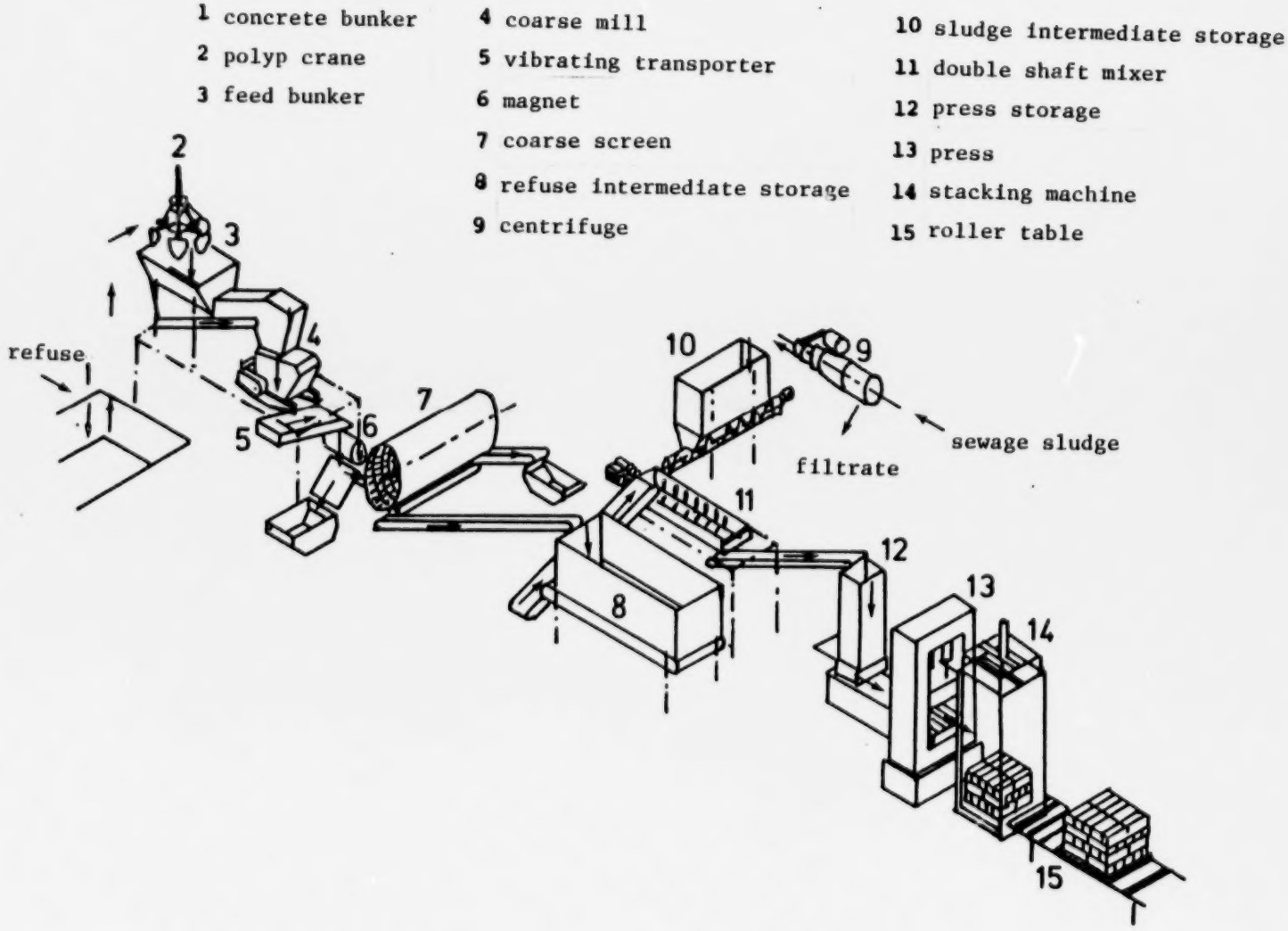


Figure 5. Schematic diagram of the Brikollare process.

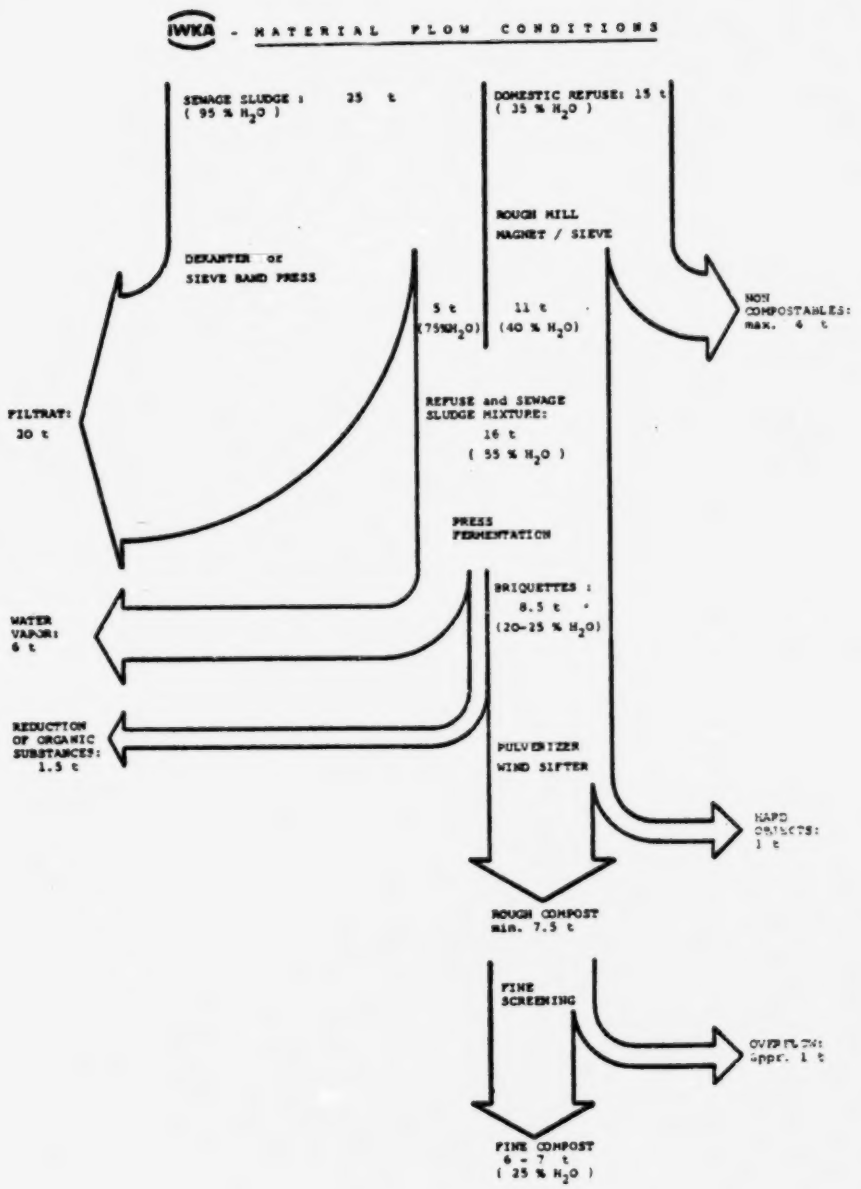


Figure 6. Brikollare material balance.
(Source: IWKA)

problems. During a visit to the Biel installation on May 6, 1978, no operational problems were apparent.

Sales prices in Switzerland in 1977 were:

- Compost for vineyards (superior 15 mm particle size) 9.50 ft*/t ($5.20/t)
- As piglet's earth 11 fr/bag ($2.80/bag) (24 ℓ, 18 kg)
- Bark compost, 1 part bark, 2 parts compost sold in 75 liter bags to the largest consumer products chain in Switzerland at 3-4 fr per bag, the retail price at the supermarket is 7.20 fr/bag ($3.90/bag).

"Bio-Manure" process--
This is a windrow composting system with additives.

Straw seems to be the most suitable additive. Though attempts have been made to produce compost with mushroom mycelium, poultry droppings, and "Biorott" (bacteria and fungus concentrate from the firm Dr. Heinrich Propfe, Manneheim), these have not been adapted by commercial installations.

The process of producing compost from sewage sludge in windrows by adding straw ("BIO-manure") was developed by the Hessische Landesanstalt für Umwelt (Hessian State Institute for Environment). Mixing straw and sewage sludge is extremely simple since it can be done with a fertilizer spreader. A layer of straw in the form of compressed bales is packed lengthwise onto the rollers. This layer of straw is covered with sewage sludge (20 percent solids) in the following proportions: 1.25 parts of primary sludge to one part of straw or 1.5 parts of digested sludge to one part of straw. It has proved practical to spread part of the straw in a thinner layer on top to obtain an even mixture. Building up the windrows is then carried out by discharging the fertilizer. The typical course of such windrow composting can be described as follows:

Phase I: Two to four days after the windrow has been set up, its temperature rises rapidly. Temperatures of over 65°C are reached in the windrow.

Phase II: The temperature level is retained for several days. Even the outer surface of the windrow becomes more than warm to the hand. Rainfall can lead to a short-term drop in temperature and to the development of steam on the surface of the windrow. These high windrow temperatures last approximately 6 to 10 days.

Phase III: The temperature gradually decreases to 40°C. The entire fermentation period lasts about 6 weeks. With an 80 hp tractor, a 6 t

*Fr - Swiss Franc ($0.55)

fertilizer, and a Caterpillar loader with a 1.5 m^3 shovel capacity, approximately 9 m^3 dewatered sewage sludge can be processed to "Bio-manure" per hour.

The profitability is largely dependent on the transport costs for straw, sewage sludge, and the finished product as well as on the purchasing price for the straw needed. To save transport costs, the processing of straw and sewage sludge should, therefore, take place in the direct proximity of the sewage treatment plant or as close as possible to the place where the compost will be used later.

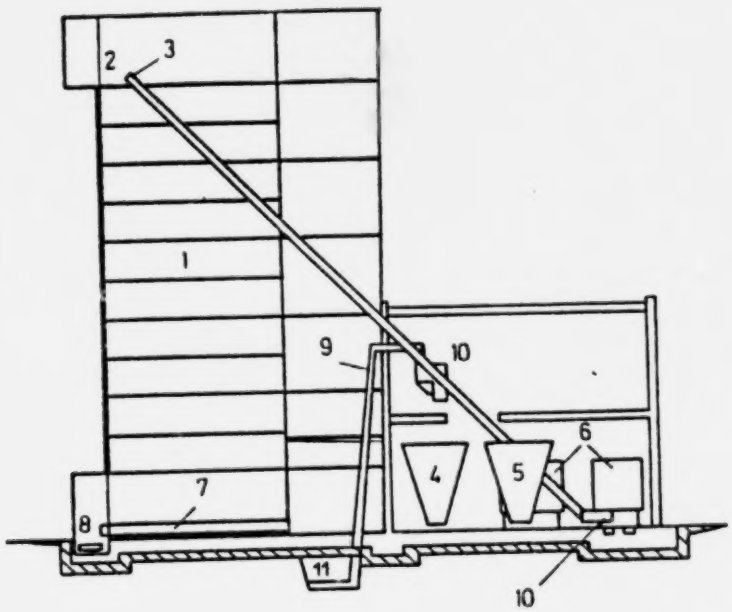
To sum up, it can be said that the extent of sludge composting in windrows using additives is slight taken altogether (one plant in Pleidelsheim near Ludwigsburg; one plant in Althausen in the Ravensburg district), even though repeated attempts are being made to achieve an improvement. The following factors can be cited as obstacles:

- Difficulties in handling the material,
- Difficulties in ensuring an even water content and sufficient aeration, within the pile,
- Problems in obtaining and mixing the additive substances,
- Dependence on the weather conditions leading to uncertain hygienic results, and
- Large space requirement.

Schnorr Valve Cell Process--

The fermenting towers used in the valve-cell process shown in Figure 7 are 10 m long, 4 m wide and 15 m high and consist of ten tiers, one above the other. The floor of each tier consists of perforated valves which can be opened and closed hydraulically. The fermentation mixture, which consists of fresh sludge with a solid content of 22-25 percent and ground-up bark with a diameter of 5-10 mm, is fed into the top tier. When the valves are opened, the material falls onto the floor below.

At the start of the process, the towers are initially filled with an equal mixture of dewatered sludge and ground-up bark. After the process is established, a portion of finished compost is recycled back into the system by mixing it with fresh sludge and bark in a 2:2:1 proportion. Thus, the quantity of ground bark required for the process is reduced. The mixer and the drag chain conveyor are located below the sludge and the recycle compost containers. The product (feedstock) from the mixer passes through a set of rubber rollers before being conveyed to the top of the tower. The purpose of running the feedstock through the rubber rollers is to further loosen the material by breaking any lumps which may have formed. This tends to keep the feedstock fluffy, and thereby increases the opportunity for aerobic composting.



1 biocell reactor
2 distributor
3 conveyor
4 sludge container
5 returns container
6 coagulant container
7 discharge conveyor
8 dump conveyor
9 sawdust conveyor
10 pumps
11 sawdust bunker

Figure 7. "Schnorr" biocell system.

Every third day, the content of the tower is let down one tier at a time by opening the floor valves so that a residence time of 30 days results. Every second tier is aerated from the front and the alternate tiers from the back. Directing the air in this way ensures that it flows through the fermentation material and not past it. The fermentation mixture is spread out in layers of 1 m deep in each tier, and, as it drops from tier to tier, further mixing and loosening occurs. Temperatures of 70°C and above are reached during a two-week fermentation period; thus, the sewage sludge is made completely hygienic. The temperature is utilized to control air flow to the process. Temperature probes are attached at three places in the fermentation towers.

Roediger/Fermenttechnik Process--

This process was developed by Professor Baader (Institute for Agricultural Technique, Brunswick) for animal wastes and has been adapted to sewage sludge (see Figure 8). Fa. Wilhelm Roediger Industriehafen has constructed only one demonstration plant which is located at Mittleres Wutachtal, West Germany.

Previously dewatered sludge is combined with dried waste in a double-shaft mixer to obtain water content of approximately 50 percent. The mixture is fed into the reactor by a vertical conveyor. Aeration in the reactor is achieved by passing air through the floor grating. At certain intervals during the fermentation process, the grating is set in motion and the material falls through a catch funnel into a screw conveyor fixed below it. The material is then fed back into the reactor via the vertical conveyor. Air is blown through the grating at such a high rate that excess oxygen is supplied. The fermentation process reaches a disinfection temperature of approximately 72-74°C within 24-36 hours. The circulation process mentioned above ensures that all the material passes through this high-temperature zone several times during the fermentation period. The material is then formed into pellets and dried.

HKS (Homogeneous Composting and Stabilization) Process--

In this process, the fermentation takes place in a rotating horizontal drum rather than in a tower (see Figure 9). Raw, dewatered sewage sludge is mixed with returns and continuously added to the compost material moving in the drum during the daily operating time. In this way, the fresh sludge is quickly absorbed. Except for start-up, no additives are used. To provide oxygen, air is supplied from below, along the whole length of the drum. The air is preheated to evaporate excess water from the compost.

Hazemag Process--

Household and industrial refuse is emptied out of the rubbish truck as they arrive into a feeding hopper. It then goes into an impact crusher where it is broken up and simultaneously mixed with the sewage sludge (see Figure 10). Windrows of the roughly crushed waste material are held for a six-month period which leads to an aerobic metamorphosis and to mineralization and disinfection. The original volume is reduced by about 80 percent by compaction. New wastes coming from the impact crusher are set up in windorws on the compacted surface; after six months, the process is repeated so that

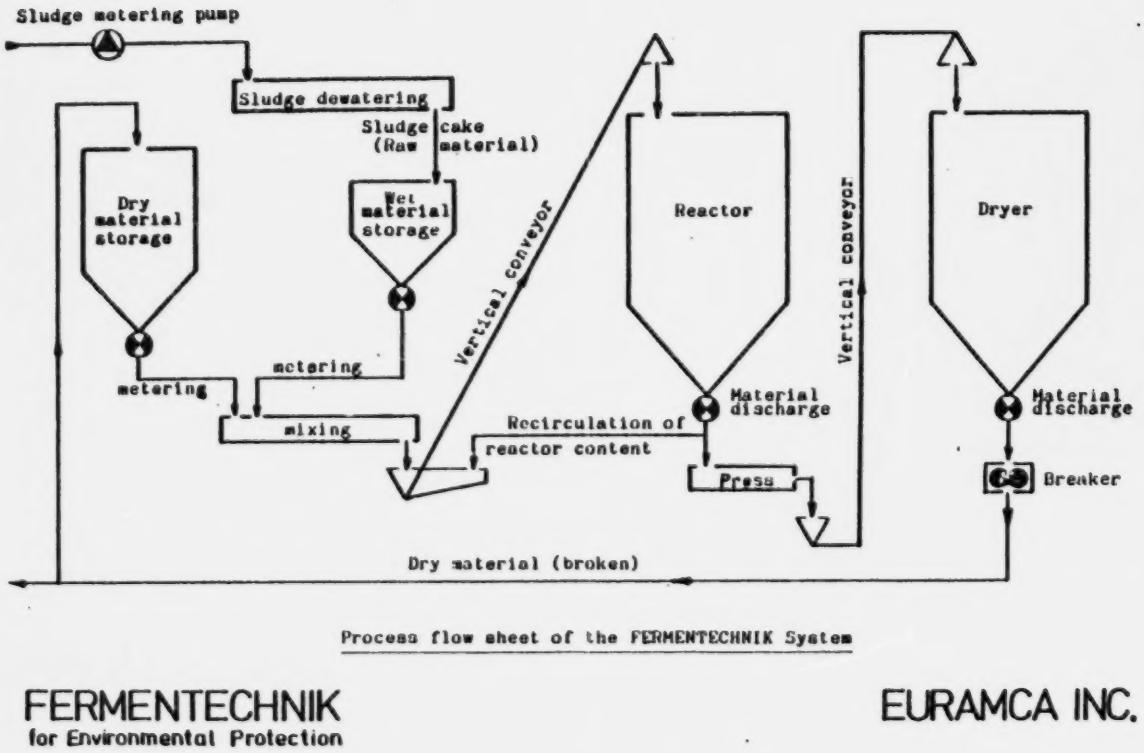
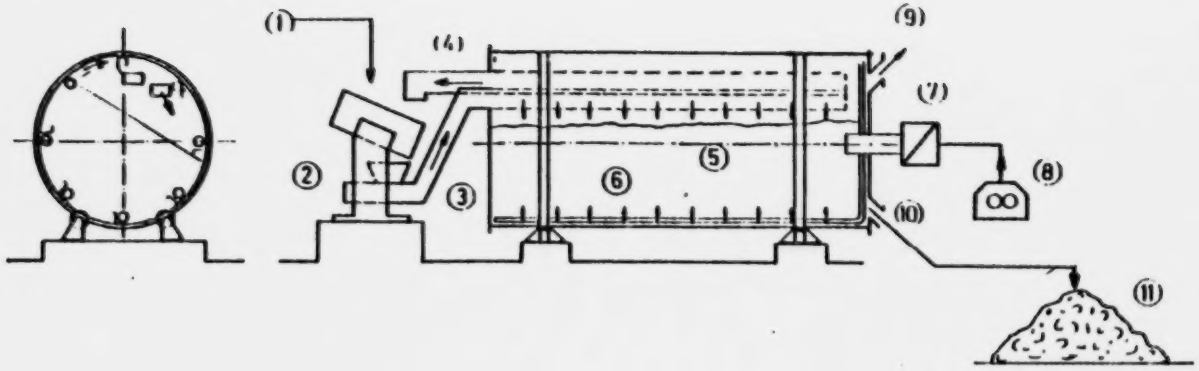


Figure 8. Roediger and Fermentechnik method.



1 mechanical dewatered raw sludge
2 compulsory mixer
3 feeding conveyor
4 discharge conveyor
5 composting drum
6 air supply
7 air heater
8 blower
9 exhaust air
10 discharge compost
11 final fermentation

Figure 9. HKS method.

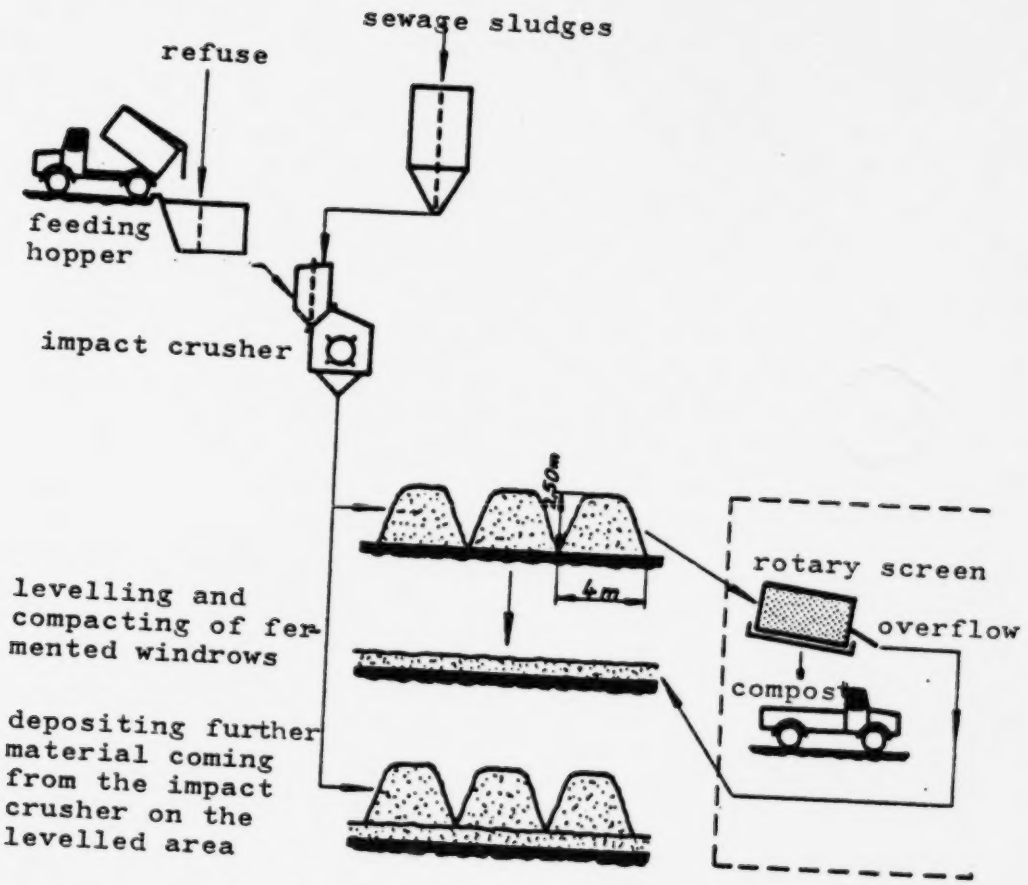
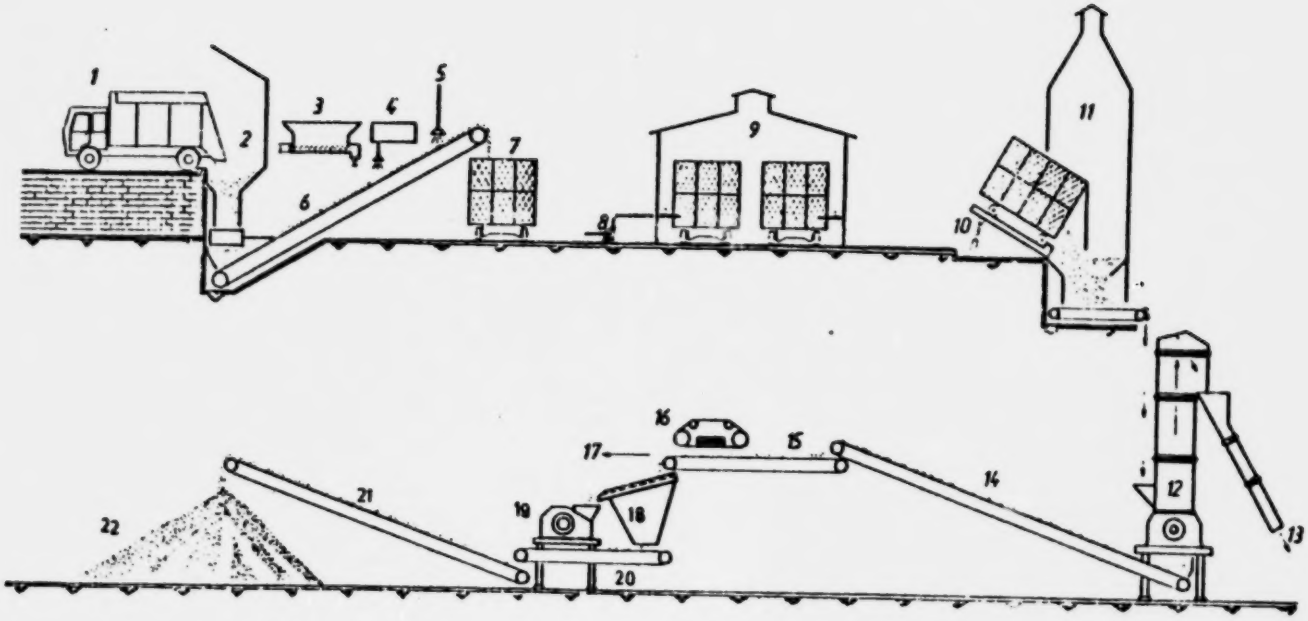


Figure 10. Hazemag dumping process.

a dumping area of only 100 m x 200 m per 100,000 residents is required. The raw product is sieved and can be used as compost.

Prat Process--

In the Prat process developed in France, the incoming refuse is emptied into a bunker (see Figure 11). The outlet mechanism is constructed so that plastic bags are torn apart and bulky pieces are broken up. The refuse and sewage sludge are taken from the bunkers on a transport belt to the fermentation cells which run on rails. A travelling platform brings the cells to the entrance of a preheating tunnel. The fermentation cells remain in the heating area about 24 hours. During this time, warm air (55°C) is forced into the mixture to initiate the fermentation and to improve the conditions for the propagation of the aerobic bacteria. From the preheating tunnel, the cell trains are shunted to a fermentation hangar where the surrounding air is circulated to ensure that sufficient oxygen for fermentation is supplied. At the end of 24 hours, temperatures of up to 65°C are reached and the cells are removed. The fermentation cells then remain for 48 hours in the area where cold compressed air is used to ensure that a temperature of 65°C is not exceeded. After five days, the cells are emptied and the raw refuse compost is crushed. The raw compost is sieved, after removing metallic scrap, and stored in windrows.



1 refuse collector
2 feeding bunker
3 compost bunker
4 tank for chemicals
5 water addition
6 conveyor
7 fermentation cell
8 compressor
9 fermentation cell
10 cell tipping device
11 metering tank
12 hammermill
13 ballistic separation
14 conveyor belt
15 conveyor belt
16 magnetic separator
17 iron scrap
18 screen
19 hammermill
20 conveyor belt
21 conveyor belt
22 raw compost

Figure 11. Prat method.

SECTION 4

EVALUATION OF THE BAV PROCESS AT HOCHHEIM AM MAIN, WEST GERMANY COMPOSTING PLANT

The major objective of this section relates to the verification of the efficiency and reliability of various composting processes. To restrict the selection of processes to a workable range, only the process which has the most plants in operation was considered. The Biologishce Abfallverwertungs, mbH & Company (BAV) process met this general requirement (see Table 1).

Biologische Abfallverwertungs, MbH & Company has constructed at least 19 plants in West Germany within the past several years and has at least 5 additional plants being designed or under construction. Most BAV reactors are designed for capacities equivalent to populations of 30,000, typical of European installations. However, BAV systems have been designed to service communities of 10,000 and cities of 110,000. Table 4 lists the locations of BAV-constructed plants in West Germany.

The BAV process has evolved from the general method that was patented by F. Kneer (German patent No. 22 53 009, June 19, 1975). Essentially, the process consists of aerating a mixture of dewatered primary sewage sludge, sawdust, and cured compost in an open-top, cylindrical vessel. The dewatered sludge, sawdust and cured compost mixture slowly descends, by gravity, through the vessel's length in about 12 days. The descending mixture is aerated by compressed air which is distributed at the base of the vessel. The composting rate can be controlled, within limits, by the aeration rate. A diagram of a general bioreactor vessel and its components is presented in Figure 12. Because the reactants descend and the air rises within the composting vessel, this process is sometimes called a "countercurrent ventilation process" (14).

An internal conveying screw removes the product from the base of the vessel. This screw rotates around the vessel's radius and brings the compost product toward a center exit port. The product, after within-vessel composting, is placed in windrows for a curing period.

CRITERIA FOR SITE SELECTION

To remain within the time and funds, only one site could be thoroughly evaluated. In choosing this site, the following criteria were established in concert with the U.S. EPA: (1) the plant be of average size, i.e., the plant should have a design capacity for processing the wastes produced by a

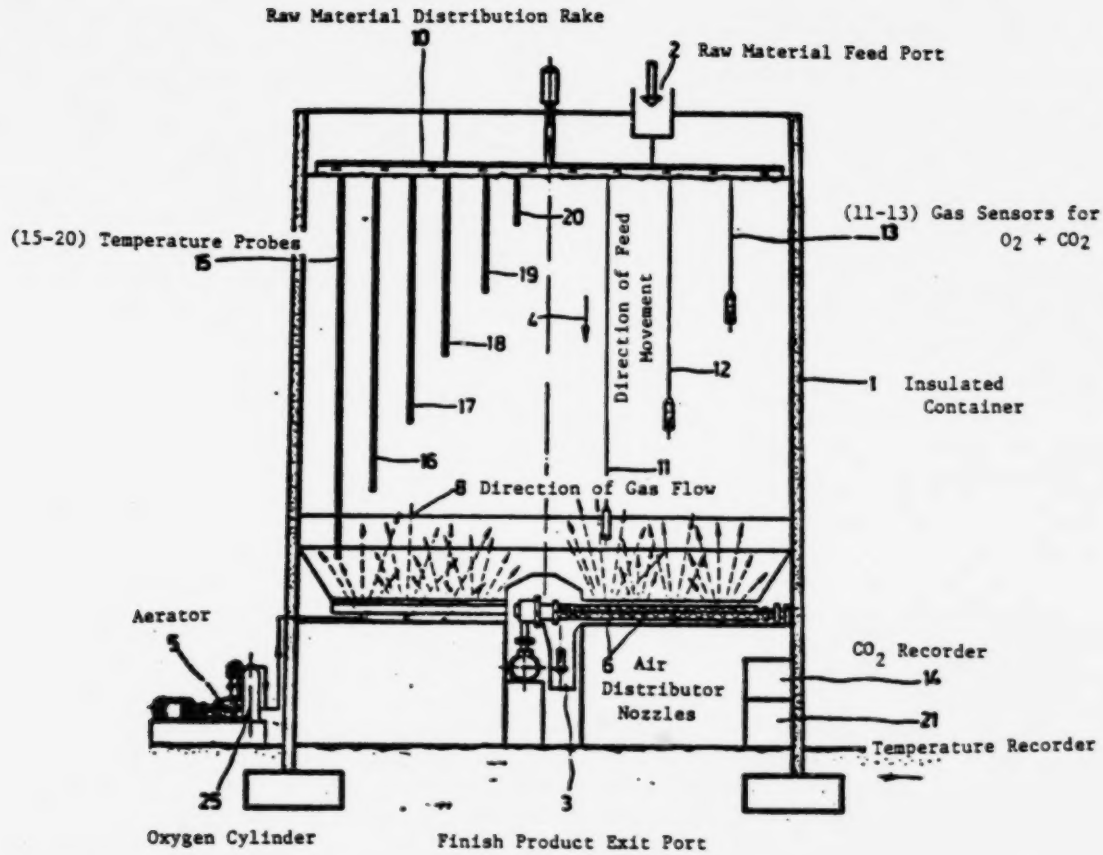


Figure 12. Kneer composting vessel*.

* German Patent No. 22 53 009, Issued June 19, 1975.

population of about 30,000 inhabitants; (2) the plant should be located in close proximity to Battelle's Frankfurt Laboratories to reduce travel time and associated costs; and (3) the plant should have more than one year of operating history so that the confusion attributed to start-up might be eliminated.

Four plants were considered and two appeared to fit all the criteria. The plants considered were at Hochheim am Main, Kronberg, Rosbach, and Ferndorftal. Figure 13 is a map of the Frankfurt, West Germany area, scaled to show the distance relationships of the four candidate BAV composting plants to Battelle's Frankfurt Laboratories. Each plant was visited before the final selection was made. The Hochheim am Main city administration officials gave their permission to perform the planned evaluations at their plant, but in view of possible expected problems in obtaining temperature and carbon dioxide concentration measurements at the Hochheim am Main plant, permission to monitor the Kronberg plant was also attempted. The temperature and carbon dioxide sensors were removed from the Hochheim reactor after the plant was placed in service; however, BAV officials offered to reinstall these sensors for the proposed evaluation. At the Kronberg plant, the temperature and oxygen measuring instruments are already installed and in operation. Moreover, the Kronberg sewage treatment plant appeared to be a better operated plant; unfortunately, discussions with the Kronberg city administrators were not favorable. The Ferndorftal and Rosbach plants are very new and had only a few months of operating history. Therefore, the final selection was reduced to the Hochheim facility.

In addition to the above site selection criteria, the Hochheim am Main plant was constructed and started operations in 1976, which is the year when several of the BAV-designed plants were put into operation. (At least 8 of the 19 operating BAV-designed plants were put on stream in 1976. The first BAV-designed plant constructed and placed into operation was in 1973.) Thus, overall, the Hochheim am Main plant was thought to be representative of a within-vessel process, although this plant does not have all of the more recent improvements such as data storage memory banks, bucket conveyors, or a vessel constructed of reinforced concrete.

A comprehensive evaluation of the bioreactor was performed on-site at the Hochheim am Main wastewater treatment plant from March 2 to June 3, 1978. The process was evaluated according to the following items: (1) reliability of the plant's mechanical components; (2) process variables which are influenced by the progress of the composting reaction such as oxygen and carbon dioxide concentration in the exhaust gas, temperature rise and temperature profile within the vessel, and the feed material's total retention time; (3) measurement of the odors originating from the site; (4) chemical and physical characterization of the feed material and the final product; and (5) cost information.

On April 18, 1978, the bioreactor was shut down, due to the failure of the product discharge mechanism for reasons that are not clear, but may have related to plant operations. The plant manufacturer (BAV) recommended, at that time, that the site be moved. After discussions with EPA personnel,

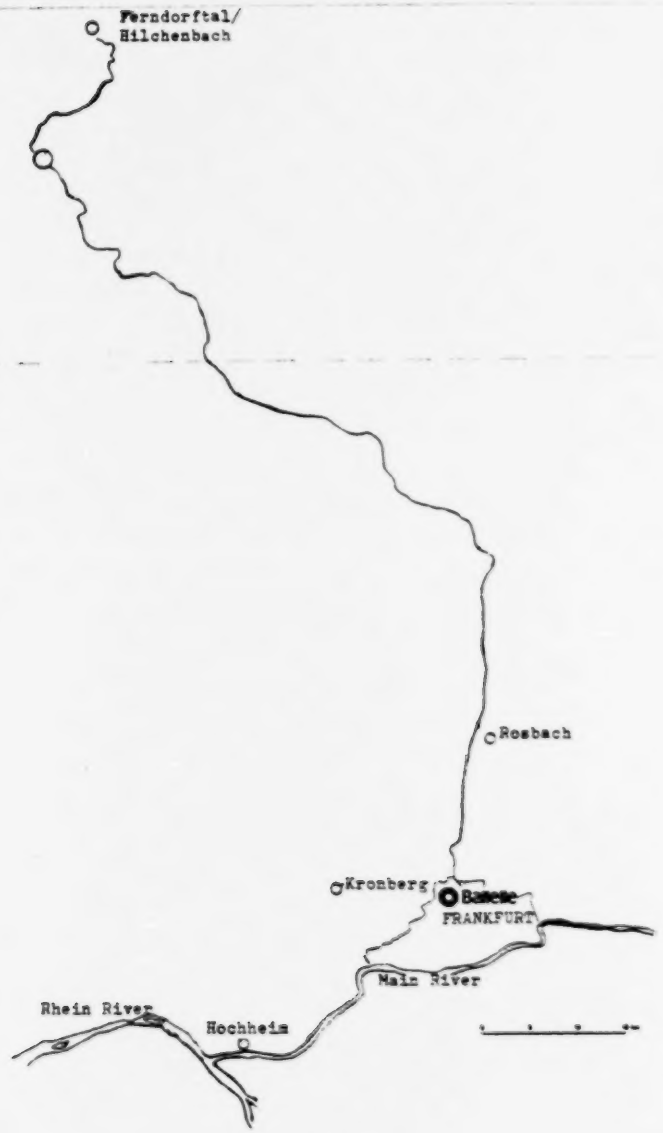


Figure 13. Location of the four candidate BAV composting plants in relation to Battelle-Frankfurt Laboratories.

it was decided in the interests of objectivity, time, and cost, to continue the study at Hochheim.

TECHNICAL DETAILS OF THE HOCHHEIM BIOREACTOR

The sewage sludge composting plant, which is a part of the Hochheim wastewater treatment plant, was planned in 1975 and has been in operation since June 1976.

The reactor has a capacity of 230-250 m^3 and was designed to serve a community of 25,000 inhabitants. The details of the sewage treatment plant design are listed in Appendix B. A process flow diagram of the Hochheim am Main composting plant is shown in Figure 14.

Sewage Sludge Dewatering

The sludge from the sewage treatment plant consists of both undigested primary and activated sludge waste. The combined raw/activated-waste sludge is pumped into the thickener vessel (417 m^3) which was originally intended to be an anaerobic digestion chamber when the plant was constructed. In this thickener, the solids content is increased from 0.8-0.85 percent to 2-3 percent. The thickened sludge is pumped into two horizontal decanter centrifuges (Flottweg, 3500 rpm, 8.3 kW) via the sludge distribution equipment. Before the sludge is centrifuged, the sludge is treated with a cationic polyelectrolyte, Sedipus 50/60 C. Polyelectrolyte rehydration ratio is 50 kg Sedipus to 12 m^3 process water and is prepared in either of the two mixing units, 12 m^3 capacity each. The sludge is then mixed by proportioning pumps with the polyelectrolyte, one part polyelectrolyte to 4.3 parts sludge. The centrifugation increases the solids content to 15-17 percent, a low value compared to American experience.

Sewage Sludge/Sawdust/Recycle Mixer and Conveyors

After thickening in the centrifuges, the sludge is transported to the sludge holding bunker by way of a drag chain conveyor. There is a recycle holding bunker for the bioreactor returns directly beside the sludge holding bunker. The fresh sawdust holding bunker is situated outside, in the open, next to the bioreactor. A dishcarge mill chain (powered by a 7.4 kW motor), fixed to a shaft in the middle of the sawdust/finished compost holding bunker, carries the sawdust out to a drag chain conveyor, which then takes it to a continuous, high-intensity, circular mixer, similar to a Banbury mixer. Thickened sludge and the bioreactor returns are transported directly to the high-intensity circular mixer by screw conveyors. Each screw conveyor is powered by 10 kW motors and is installed in the bottom of the two holding bunkers. The high-intensity mixer is powered by an 11 kW motor and has a mixing capacity of 6 m^3/hr. The feedstock mixture (33-1/3 percent sludge, 33-1/3 percent sawdust, 33-1/3 percent returns, i.e., 6.25 m^3/d sludge, 6.25 m^3 sawdust, 6.25 m^3/d returns) falls onto a drag chain conveyor which takes it directly to the top of the bioreactor. The sludge feedstock preparation

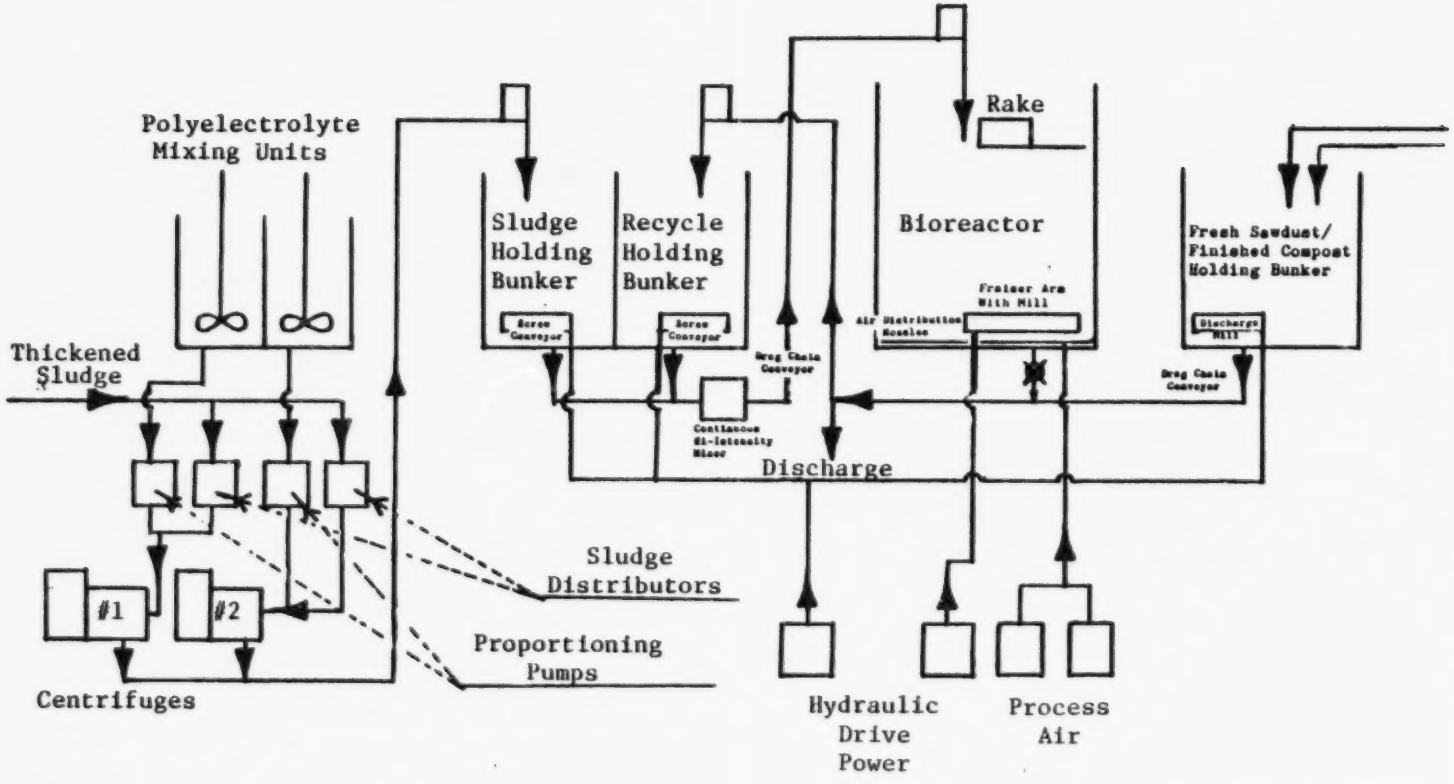


Figure 14. Process flow diagram of the Hochheim am Main composting plant.

usually takes about 2 hours per day. It should be noted that the design for mixing was 50 percent sludge, 40 percent recycle, and 10 percent sawdust.

The Bioreactor

The bioreactor is an 8 m high steel tower (diameter: 6 m; capacity: 230 m^3) insulated with styrofoam with an outer covering of corrugated sheet metal. (Figure 15 is a recent photograph of the Hochheim bioreactor.) The reactor is covered with a roof 80 cm above the top of the reactor. A service gangway runs across the diameter of the reactor. The sludge mixture is mechanically conveyed to the top of the reactor at the rate of 18.75 m^3/d. The surface of the sludge mixture is leveled out with an equalizer (revolving rake).

Inside and at the bottom of the bioreactor, there is a rotating extraction device (fräiser arm discharge mill chain powered by an 11 kW motor) and the air distribution system. The fräiser arm rotates and travels on a track around the reactor's circumference. On this arm, there is a moving drag mill chain which brings the product toward the center and into the exit port. One of the two rotary vane blowers (each 15 kW) directs approximately 600 m^3 of air per hour through the compost material. The composting mixture is aerated approximately 22 hours per day. There are 3 temperature measuring probes and one carbon dioxide measuring probe fixed at 30 cm off the inside wall, and out of the path of the equalizing rake. All 4 probes are fixed at one point directly beneath the bioreactor's feed conveyor. The temperature measuring probes extend into the compost to 3 depths, 160 cm, 200 cm, and 240 cm, from the bioreactor's fill line. The single carbon dioxide measuring probe is attached to the 200 cm temperature measuring probe. It should be noted that the carbon dioxide probe was inoperative during this study, and consequently, portable gas analyzers were used.

The compost is taken out of the reactor after about 12 days, based on the input feed rate (18.75 m^3/d) and assuming plug flow. Part of it is fed back into the reactor as returns (6.25 m^3/d) while the rest is composted for 5-6 weeks in windrows. There are no values on fermentation shrinkage during windrow composting. A flow diagram of the process showing volumetric flow is presented in Figure 16.

MECHANICAL RELIABILITY OF THE COMPOSTER COMPONENTS AT THE HOCHHEIM AM MAIN PLANT

From observations during the on-site study of the composting plant from April 12 to April 18, 1978, and according to reports by the sewage treatment plant foreman and the Hochheim city engineer, it appears that components most susceptible to failure at the Hochheim composting plant are (1) the product discharge mechanism in the bioreactor (fräiser arm with mill); (2) the discharge mechanism in fresh sawdust/bunker (discharge mill, Figure 14); and (3) the continuous, high-intensity, circular mixer. The sludge centrifuges, rotary vane blowers for the air supply, rake equalizer at the top of the bioreactor, and the drag chain conveyors, on the other hand, can be regarded as reliable and require only normal maintenance.

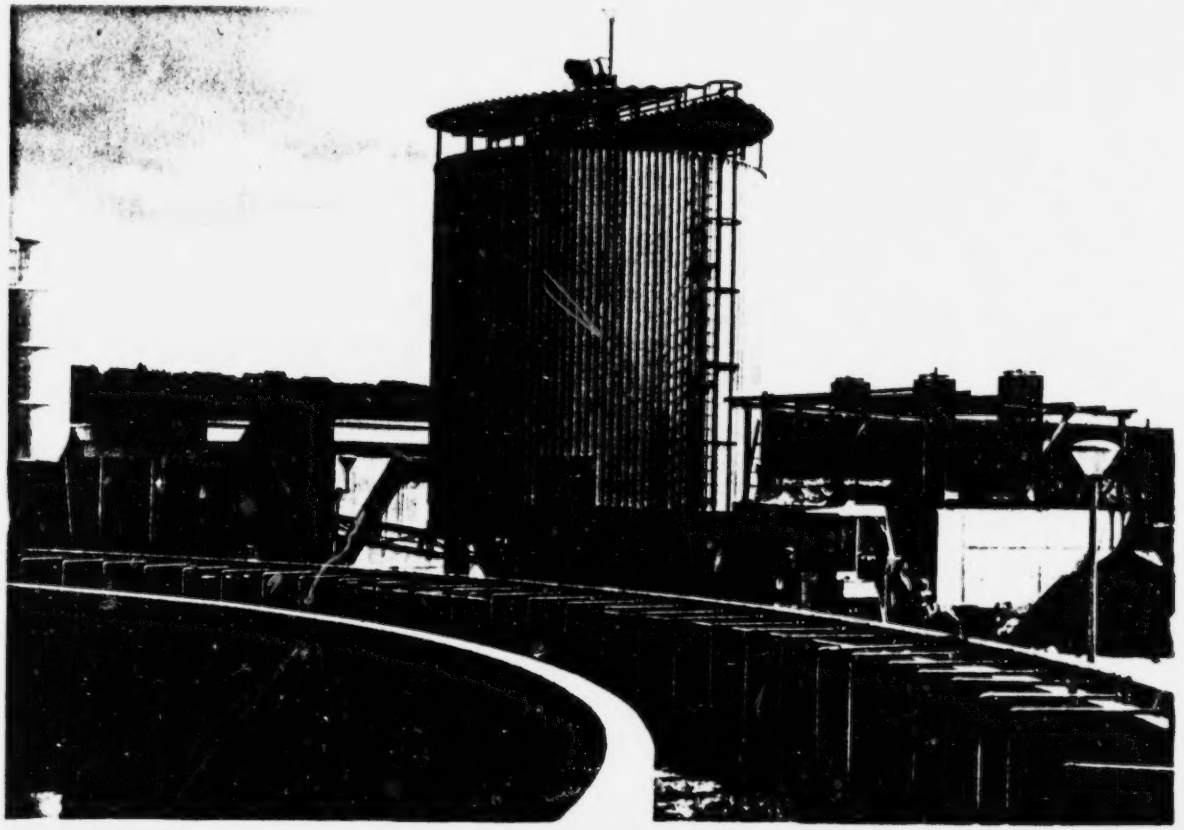


Figure 15. The BAV bioreactor at the Hochheim am Main, West Germany wastewater treatment plant.

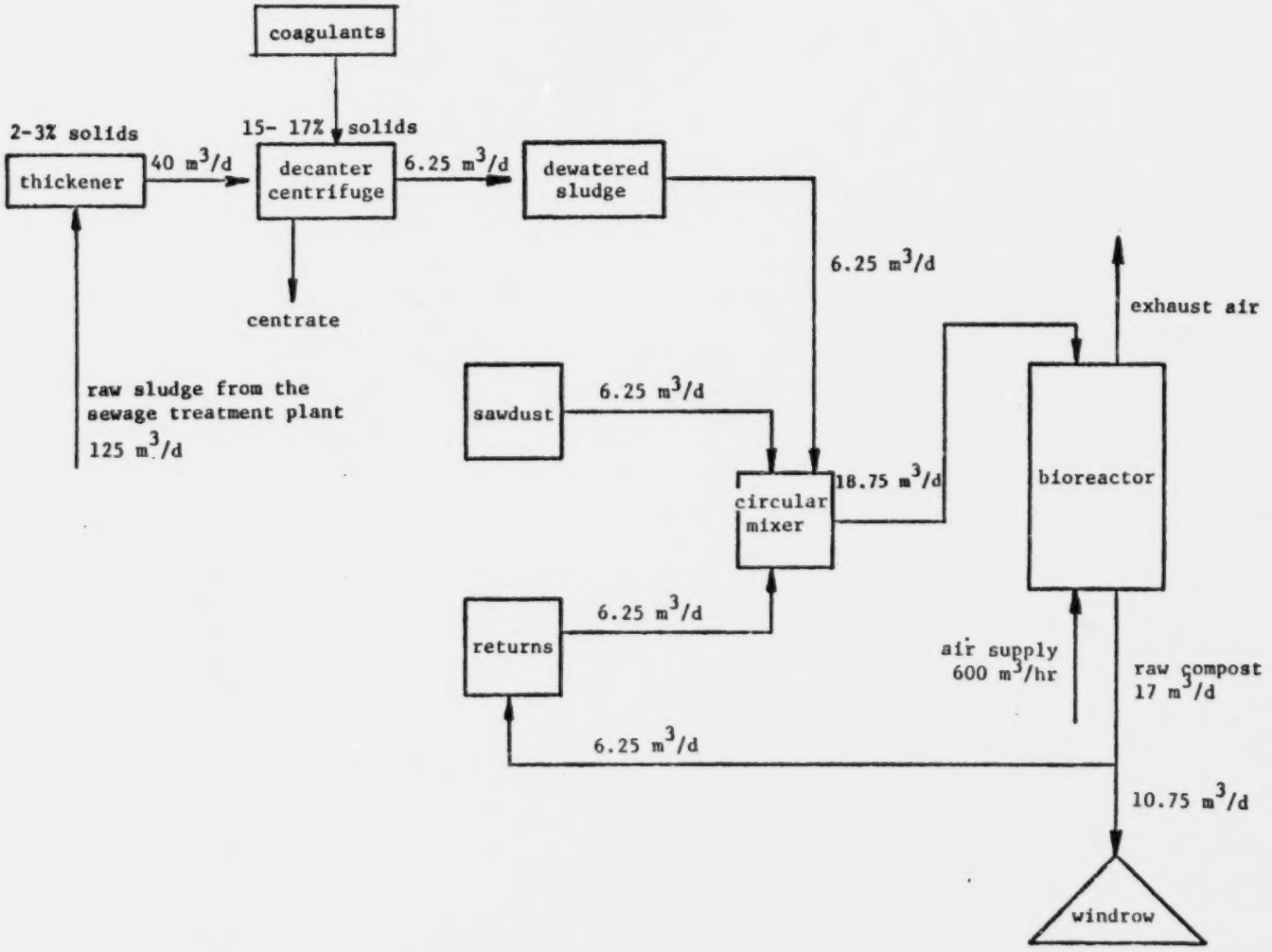


Figure 16. Volumetric flow diagram of Hochheim composting plant.

Since plant start-up in 1976, there have been four major failures in the bioreactor's product discharge mill. These failures caused the plant to shut-down for 2 to 4 weeks. During the shut-down and before repairs could be made, the bioreactor had to be emptied manually. The causes of each failure were recorded in the wastewater treatment plant's log and the following explanations were given:

- Mill chain on fräiser arm broke apart
- Fräiser arm bent upright, shaft broke off (agglomerated material on the floor of the reactor)
- Fräiser arm stopped (agglomerated material on the floor of the reactor)
- Fräiser arm stopped (the fermenting mass agglomerated on the floor of the reactor). This was attributed to the fact that the direction of the air flow through the reactor was reversed from normal operation. The moisture in the outside air condensed and accumulated in the base of the reactor. The condensed water reacted with the sludge/sawdust mixture to form a solid mass.

While the proximate course of these failures is clearly formation of agglomerated masses, it is unclear whether this was the result of poor operation or a deficiency in the equipment design.

The discharge mill in the sawdust bunker has broken 3-4 times since start-up. Each time the center shaft broke. Since the sawdust bunker is not roofed, the sawdust absorbs rainwater readily, which in turn reacts to form a solid mass. (However, this can be easily corrected by roofing the bunker and using a coarser screen fraction of sawdust.)

The motor in the continuous, high-intensity, circular mixer has been replaced three times. The latest replacement is rated at 11 kW. The first two motors (7.5 kW and 9 kW, respectively) were insufficient. In addition, mixing blades broke when large pieces of wood in the sawdust entered the mixer. In one case, these blades became wedged into the drag chain conveyor below the mixer.

MECHANICAL RELIABILITY OF COMPOSTER COMPONENTS AT FIVE OTHER PLANTS

To further assess the mechanical reliability of this particular bioreactor system, operators at five other BAV composting plants were interviewed. The result can be summarized as follows:

Two plant operators give the plant positive ratings, two neither positively nor negatively, and one negatively. However, all operators cited difficulties with the bioreactor's fräiser arm discharge mill, three (in contrast to Hochheim) with the drag chain conveyors, two with the high-

intensity mixer and one operator reported that no part of the plant was trouble-free. One operator had difficulty with the discharge mechanism in the returns and sludge bunker before the discharge chains were substituted with screw conveyors. One operator reported that bridging formed in the bioreactor during the product discharge cycle. The bridging is characterized by a depression in the level spots, indicating localized high solids removal rates.

The difficulties with the drag chain conveyors and the high-intensity mixers were generally viewed as possible deficiencies in the system which may require developments as initiated by BAV in new plants. These improvements include:

- The breakload on the fräiser arm mill chain has been doubled to 24-25 tons from 12 tons.

- Plastic bucket conveyors and conveyor belts have replaced the drag chain conveyor. The plastic bucket conveyors now lift the feed input into the reactor (vertical movement) while belt conveyors are used where product is moved horizontally.

- Fresh sawdust, the bulking agent, is now stored by itself in an independent bunker, rather than being stored with the cured compost.

- Variable speed hydraulic motors are substituted for the fixed-speed electric motors for powering the fräiser arm mill chain and the high-intensity mixer.

- The new bioreactors are to be made of reinforced concrete and tapered at the top. With the wider bottom, the product may fall more easily and thus decrease the product bridging problem.

It should be noted that the above observations are based on direct comments of plant operators. No attempt was made to assess whether or not operating condition at these plants were comparable, that is, moisture content, mixture rate, maintenance, level of skill, etc. While beyond the scope of this effort, such data would be relevant in assessing overall failure characteristics and should be done in future studies.

Overall, it is difficult to evaluate the reliability of the system's mechanical components due to the following reasons:

- Operator's mechanical skills and level of training are different,

- Sewage sludge characteristics vary from treatment plant to treatment plant,

- Feedstock mixture ratios vary at each composting plant.

TEMPERATURE PROFILE AND EXHAUST GAS COMPOSITION

Longitudinal Temperature Profile

The temperature within the reactor is recorded on strip charts in the control room. The three thermocouple probes extend into the compost at approximately 160 cm, 200 cm, and 240 cm from the reactor's fill line at one point. The temperature was recorded throughout the on-site evaluation study period and is plotted against the data in Figure 17. The data showed that the reactor temperature varied from over 45°C to 90°C, at the time when the reactor was being operated. On April 18, the reactor product-discharge mechanism failed. The reactor was emptied manually so that the discharge mechanism could be repaired. The temperatures recorded and plotted during that down period, April 18 to May 18, is that of the ambient air.

Exhaust Gas Composition

The exhaust air composition was measured at three locations on the top of the bioreactor: Point 1 is 80 cm from the center, Point 2 is 180 cm from center, and Point 3 is 280 cm from center. Table 8 lists the dates when the concentrations of oxygen and carbon dioxide were measured by Dräger tube method. The oxygen concentration averaged 17.2 percent in the central circular area (80 cm radius) and 18.3 percent in the outer circular area, 80 cm from the center to the reactor's inside wall. The carbon dioxide concentration followed a similar pattern; the highest concentration was measured in the center of the reactor, 3.9 percent. In the outer ring, 80 cm from the center to the reactor's inside wall, the carbon dioxide concentration averaged 2.2 percent. The significance of these findings is that this is indicative that air is channeling through the reactor rather than diffusing uniformly throughout. Visual inspection of the compost surface at the top of the reactor correlates with these measurements. The compost in the reactor's center (80 cm radius) consisted of a loose-textured material, while the compost in the outer zone was solidified and crusted. Cracks propagated throughout this crusted area. Air evidently traveled through these cracks, and, as indicated by the low percent CO_2, accomplished very little composting.

PROCESS ANALYSIS BY CHEMICAL AND PHYSICAL METHODS

One method of evaluating a process is by chemical and physical analysis of its input and output. To accomplish this evaluation, representative samples of feedstock and composted product were analyzed. The samples were collected over a two-month bioreactor operating period, during which time a breakdown of the product extraction mechanism occurred. The repair of the product extracting mechanism required manual unloading of the reactor contents followed by the refilling of the reactor with freshly prepared feedstock, with no removal of product until the vessel was filled. One month elapsed from the time of breakdown, unloading, repairing, refilling, and returning to normal operations. Thus, this evaluation represents the process performance at two stages of the plant's normal operation, (1) after

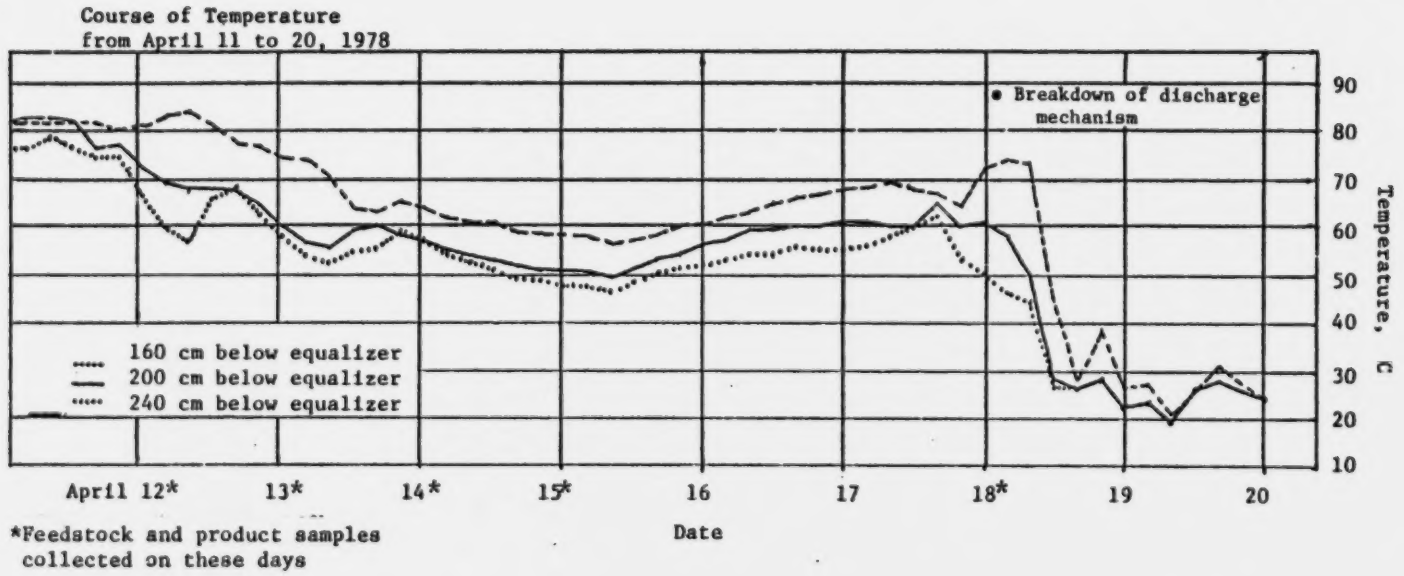


Figure 17. Temperature profile at Hochheim bioreactor.

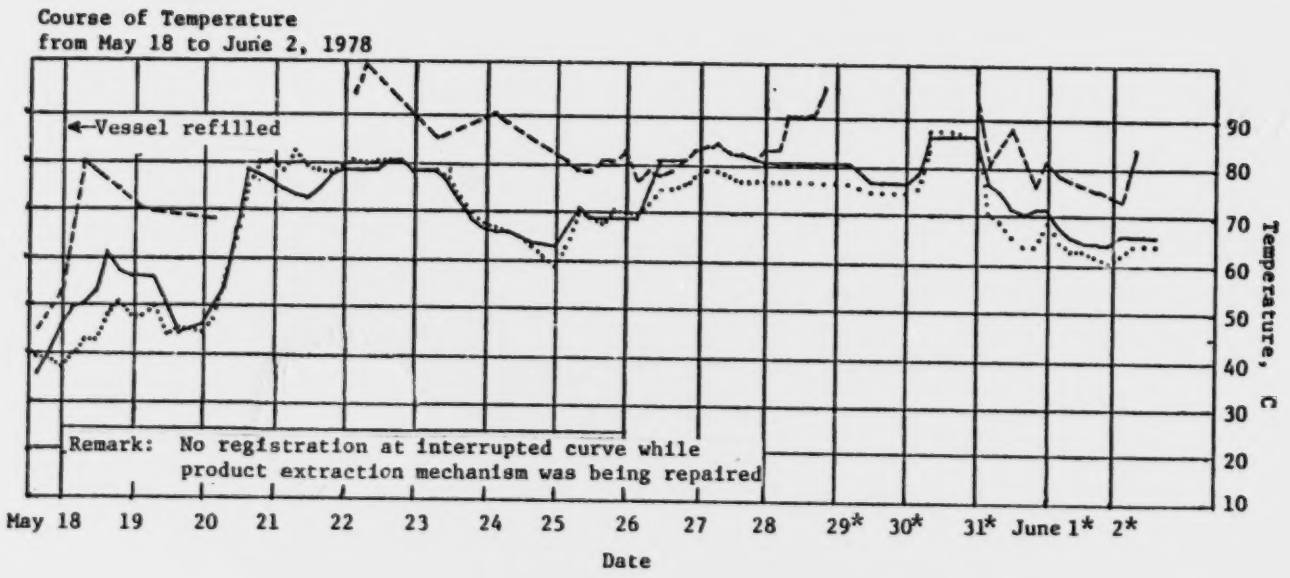


Figure 17. (continued)

TABLE 8. GAS COMPOSITION OF BIOREACTOR EXHAUST GAS
(Dotted line indicates samples taken before and after breakdown of product extractor)

Date	Measuring Point 1		Measuring Point 2		Measuring Point 3	
	vol.% O_2	vol.% CO_2	vol.% O_2	vol.% CO_2	vol.% O_2	vol.% CO_2
04/12/78	-	-	15	2.0	-	-
04/13/78	16	3.8	20	0.6	18	0.9
04/14/78	-	0.4	20	0.1	17	0.3
04/17/78	17	2.0	21	0.1	20.5	0.2
04/18/78	19.5	0.6	21	0.2	20	0.3
05/29/78	20.5	2.0	20	0.6	-	-
05/30/78	17.0	4.0	16.0	7.0	18.5	4.8
05/31/78 (1)	18.0	0.2	18.5	4.0	18	1.5
05/31/78 (2)	16.0	6.0	14.0	7.0	18	0.8
06/01/78	15.0	10.0	19.0	2.0	14.0	9.5
06/02/78	15.5	10.0	19.0	1.0	19.0	0.6
Average	17.2	3.9	18.5	2.2	18.1	2.1

Measuring point 1: ~ 80 cm from center
Measuring poont 2: ~ 180 cm from center
Measuring point 3: ~ 280 cm from center

relative error: 5-10 %

an extended period of operation, and (2) at the beginning of a normal period of operation. The complete analytical data and methods of chemical analysis are detailed in Appendix D.

Sludge Solids Analyses

The study of compost solids is a measure of (1) the amount of solid material, (2) the proportion of organic matter, and (3) the mineral, or the inorganic fraction. The organic portion is the food for the bacteria associated with composting. The results of these analyses indicate the progress of the decomposition of the organic components. As decomposition progresses, the concentration of organics will decrease as the proportion of organics is converted to gases and inorganics. Also, the proportion of total solids will increase as water is depleted from the solids by evaporation. Fresh raw sludge usually contains approximately 70 percent organic matter of the total solids and is highly odorous. Well digested sludge as found in compost usually has an organic content of less than 50 percent of the total solids and is not odorous.

In the solids content study of the Hochheim am Main bioreactor process, the organic constituent contents of the feedstock and the composted product (both before and after the mechanism failure incident) were analyzed at 76 percent of the total solids (Table 9). The total solids in the product increased from 33.2 to 39.6 percent due to the evaporation of water. The data suggest that the Hochheim plant does not stabilize sewage sludge completely. The low solids content of the feedstock is worthy of note. Most composting processes start with a feed with at least 40 percent solids. Some of the "agglomeration" problems encountered may be explained by excessive moisture in the feed. One must recognize these factors when comparing this data to data from other process systems.

Elemental Analysis

The intent for conducting this study was to obtain a heat balance around the system, such as in a combustion chamber. However, the analyses for carbon, hydrogen, nitrogen, oxygen, sulfur, and heat values show no difference between feedstock and composter product (Table 10).

Odor and Appearance of Final Product

Visual and odor tests showed no difference between feedstock and the product. Both had highly putrid odors.

Operational Factors Affecting Data

After the reactor is filled and the composting process starts, the temperature increases to 70-80°C. (This plant recorded 95°C on May 29.) In the BAV process there is no provision for internal mixing; the compost design relies upon gravity to move the reaction mixture uniformly through the reactor.

TABLE 9. COMPARISON OF FEEDSTOCK AND COMPOSTED PRODUCT OF THE HOCHHEIM AM MAIN, WEST GERMANY BIOREACTOR, APRIL 12 TO JUNE 2, 1978

	Sample collection period	Total solids, 105 C %	Organic solids, %		Ash, 900 C %
			Total	% of Total	
		Before Extraction Mechanism Failure			
Feedstock (3)[a]	4/12	32.7	25.8	79.0	6.86
	to				
Vessel product (5)[a]	4/18	35.1	26.5	75.4	8.64
		After Extraction Mechanism Repair			
Feedstock (4)[a]	5/29	33.5	24.6	73.3	8.93
	to				
Vessel product (5)[a]	6/2	44.1	34.2	77.5	9.94

a Number of samples analyzed for that group; samples were collected on different days during the collection period.

$$\% \text{ Organic Solids} = \frac{\% \text{ Dry Solids} - \% \text{ Ash}}{\% \text{ Dry Solids}} \times 100$$

TABLE 10. CHEMICAL COMPOSITION COMPARISON OF FEEDSTOCK AND COMPOSTED PRODUCT FROM THE HOCHHEIM AM MAIN, WEST GERMANY BIOREACTOR, APRIL 12 TO JUNE 2, 1978

	Sample collection period	Chemical elements, Percent					Heating value,[a] kJ/kg
		C	H	N	O	S	
		Before Extraction Mechanism Failure					
Feedstock	4/12	46.3	5.7	1.6	36.2	0.25	17042
	to						
Vessel product	4/18	44.8	5.5	1.5	36.3	0.31	16684
		After Extraction Mechanism Repair					
Feedstock	5/29	45.9	5.7	1.3	36.7	0.20	16905
	to						
Vessel product	6/2	44.4	5.4	1.6	36.4	0.25	16658

(a) Total mass basis, including ash

The organic constituents of the reaction mixture tends to agglomerate, or gelatinize at the composting temperatures of 70-80 C. Since no provision for either internal mixing or bed loosening is provided in the mechanical design, the compost mixture can compact. The product removal mechanism failure of April 18 was attributed to product agglomeration at the base of the reactor*. A possible conceptual view of the internal condition on April 18, may be illustrated, for example, by Figure 18. In addition, the product removal part is centrally located under the feedstock filling conveyor. A natural propensity for form a cone is established, where the product flow outside the cone is lower and that in the center is higher than the average value for the entire process.

Thus, the feedstock filled at day zero in time, is removed at some time which is shorter than one would calculate from the empty volume of the reactor and the volumetric feed rate.

The formation of a "sticky" mass is a key tenet in this explanation, and this was observed quite strikingly at Hochheim, and to a lesser extent at other plants visited [Kronberg, Rosbach, and Ferdorftal (Seigen)]. It is believed that there was a greater propensity to form this mass as the proportion of sludge used in the feed material was increased. Furthermore, the use of unstabilized recycle material would tend to aggravate this process. This may have been the cause for the agreement between feed and product chemical analysis data obtained from the Hochheim plant. If over-loading with insufficiently dewatered sludge is the source of the problem, it is likely that increasing the mass of bulking agent or properly stabilized compost will improve operation. However, throughput rate of fresh sludge will correspondingly be reduced.

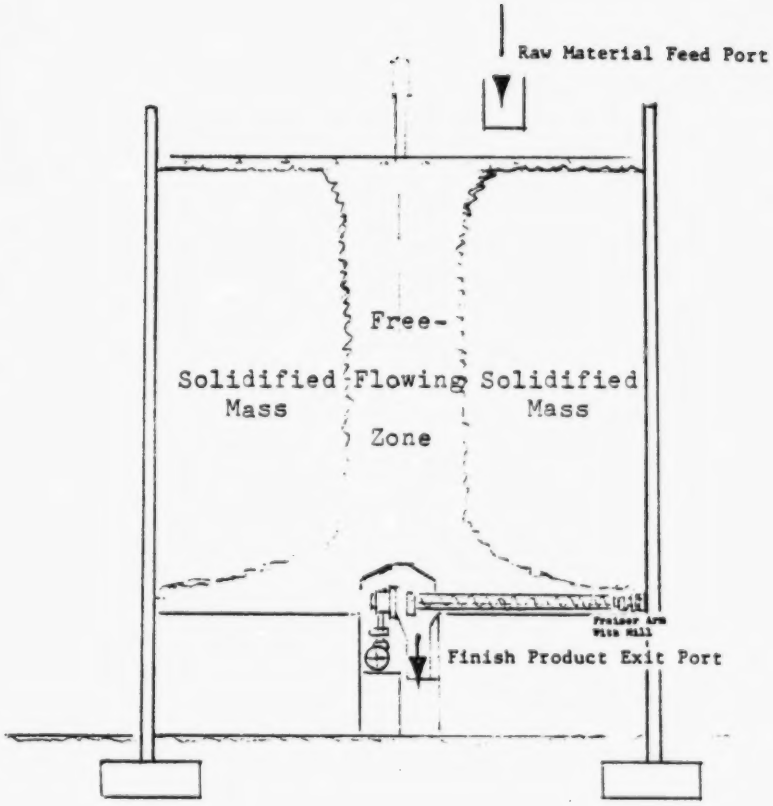
EVALUATION OF ODORS EMITTED FROM COMPOSTING PROCESS

The three major odor sources of the Hochheim am Main sewage treatment plant appear to originate at the

- Activated sludge tank,
- Bioreactor, and
- Windrows.

The odor qualities were determined organoleptically and the odor intensities were identified by determining the detection threshold level by human sense of smell (see Appendix E). The most intensive odor emission was measured

*The solid product at the base of the vessel was described as similar to "concrete". Picks and shovels were required to remove the material.



NOTE: Not to scale

Figure 18. Conceptual view of the Hochheim am Main bioreactor at time of product removal mechanism failure, April 18, 1978.

during emptying of the bioreactor. This strong emission results from the evaporation of the warm vapors steaming from the freshly processed compost while it is transferred to the curing windrows. The odor intensities determined at the windrows and the activated sludge tank were 25 and 16 percent, respectively, of the predominating odor emitted from the bioreactor. The emission intensities and qualities vary, e.g., in seasonal and working-day cycles. In Appendix E, a discussion of odor measurement technique and theoretical considerations concerning odor distribution in the surrounding neighborhood is described.

Odor concentration in the vicinity of the Hochheim plant depends on topographic and weather conditions, especially on wind direction and speed, and on turbulence. The three odor sources or odor profiles are considered and it is usually the odor from the bioreactor or a mixture from bioreactor and windrow odor which predominates, whereas the odor from the activated sludge tank is practically not perceived outside the plant area. As a result of topographical factors, odor concentration zones may form whose characteristic odor profiles may be temporarily perceived at a distance of several hundred meters.

SECTION 5

ECONOMIC EVALUATION OF BAV PROCESS BASED ON THE HOCHHEIM COMPOSTING PLANT

Operating and maintenance costs and capital investment costs were estimated for the BAV process based on equipment specifications and operating requirements as operated by the City of Hochheim. The Hochheim composting plant is designed to process 250 m^3 per day of combined sludge from the sewage treatment plant which is equivalent to 2.0 t of dry solids/day and serves a population of approximately 25,000. The plant throughput is currently estimated to be 50 percent of the design capacity or 125 m^3 of sludge per day. Details of the process which were supplied by the Hochheim City Engineer are given in Appendix F. The reader is cautioned that other sites employing the BAV process could have significantly different economics.

The largest plant now in operation which uses the BAV process is the Siegen plant which has two reactors with capacities of 350 m^3 of sludge per day and serves a population of 110,000. A capacity of 350 m^3 for the bioreactor could represent a practical limit due to the restrictions in the design of the reactor. The physical problem of drawing compost from the extremities of a vessel of much larger diameter and maintaining air distribution are believed to be the major barriers which could prevent the use of larger vessels. Therefore, the bioreactor itself may limit any economy which can be achieved by increasing the size of the plant.

A flowsheet for the BAV installation at Hochheim is illustrated in Figure 19. The capacities of each component in the process are listed in Table 11.

The installed costs for each equipment item were supplied by the City of Hochheim in Deutsch marks (DM). These costs were converted to dollars based on the exchange rate of 2 DM per dollar. An independent estimate of the installed costs was then made using the equipment specifications supplied by the Hochheim personnel. These values of the installed equipment costs, as well as the equipment specifications, are detailed in Table 12. The estimated costs are 18 percent higher than the actual reported costs which is within the accuracy of the cost estimate method used; the estimate of the total installed costs is $816,000 compared to an actual installed cost for the Hochheim facility of $690,000. The estimated installed costs include instrumentation, piping, electrical, concrete, steel, paint, and insulation. These items are listed separately in the actual costs column.

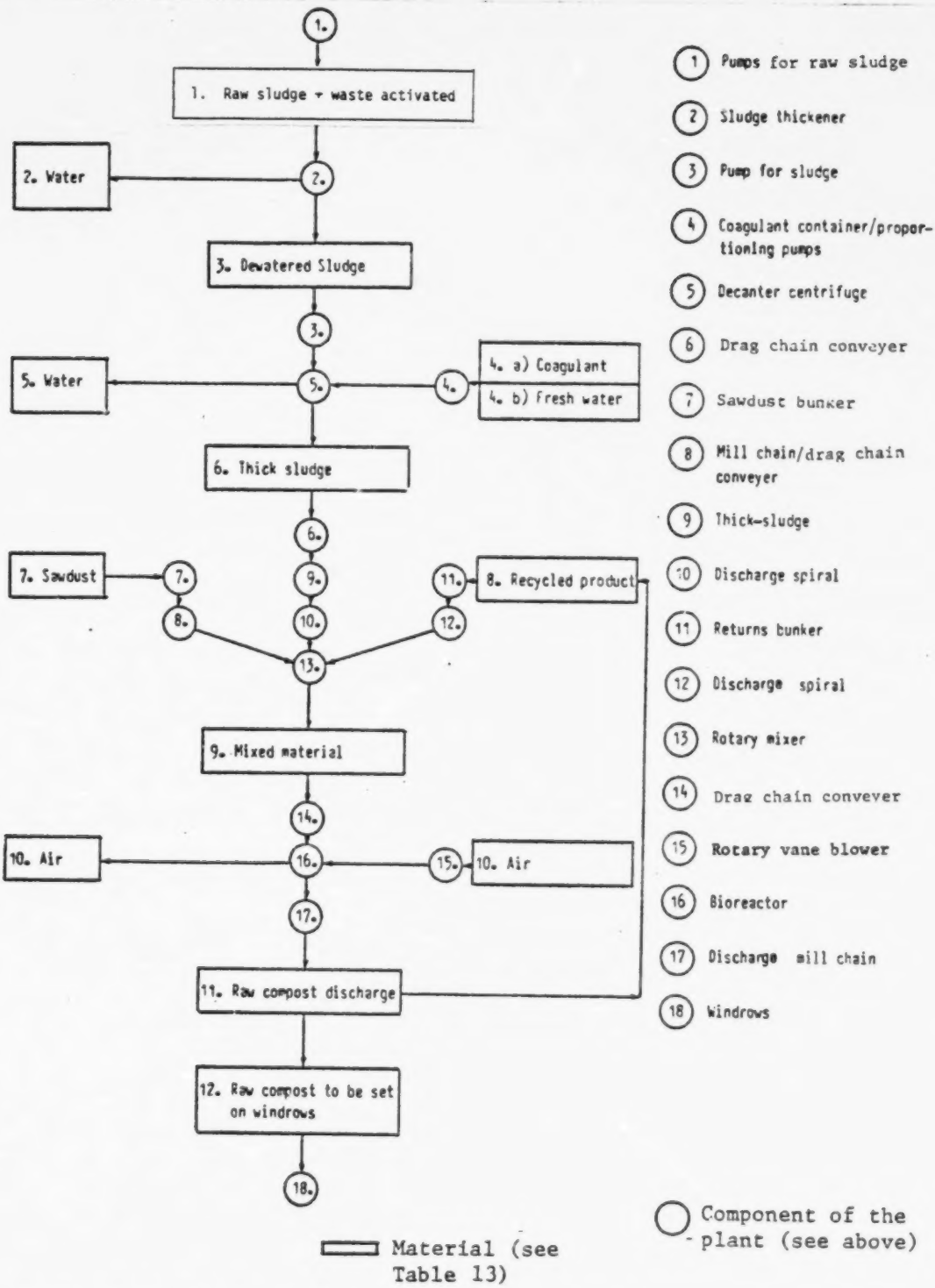


Figure 19. Flow sheet of the BAV Hochheim sludge treatment facility.

TABLE 11. HOCHHEIM PLANT THROUGHPUT BY TYPE OF MATERIAL

Type of material	Volume m^3/d	Solid matter content: % of weight
1. Primary sludge from the sewage treatment plant + waste activated	125	0,8
2. Water from sludge thickener	85	0
3. Dewatered sludge	40	2.5
4. a) Coagulant (in t/d) b) Fresh water	0.05 12.0	 0
5. Water from decanter centrifuge	45.8	0
6. Thick sludge from decanter centrifuge	6.25	16
7. Sawdust	6.25	80 - 90
8. Recycled product	6.25	36
9. Mixed material	18.75	32
10. Air	13.200	0
11. Raw compost discharge	17.0	36
12. Raw compost to be set on windrows	10.75	36

TABLE 12. INSTALLED EQUIPMENT COSTS FOR A 250 m^3/DAY SLUDGE PLANT

Item	No. required	Design basis	Unit size or capacity	Equipment Costs[a] Actual Hochheim $	Installed cost, $ (BCL estimate)
Pumps for conveying sludge to thickener	3	carbon steel 250 m^3/d 0.8% solids	83 m^3/d	13,700	10,000
Sludge thickener	1	125 m^3/d concrete	9.5 m D x 6 m H	17,800	19,600
Pump-sludge feed to centrifuges	1			3,300	2,400
Pipeline-thickener to centrifuge	1			12,500	(costed as general facility)
Coagulant container (with agitator)	2	concrete	12 m^3	4,500	5,400
Proportioning pumps	2	1500 ℓ/hr		5,600	3,400
Pipeline to centrifuge	1			5,400	(costed as general facility)
Centrifuges	2	6 m^3/hr	3500 rpm, 8.3 kW	88,400	147,800
Drag conveyor	1	6 m^3/hr		26,800	39,300
Sawdust bunker	1	concrete	35 m^3 capacity 4.5 m x 4.5 m x 1.7 m H	13,000	4,300
Mill chain	1	6 m^3/hr	7.4 kW motor	4,800	--
Drag conveyor	1	6 m^3/hr			51,800
Thick sludge bunker	1	concrete	2 m x 2 m x 2 m	(Part of Auxiliary Facilities)	500
Screw conveyor	1	4 m^3/hr		10,900	19,600
Return bunker	1	concrete	2 m x 2 m x 2 m	--	1,100
Screw conveyor	1	3 m^3/hr	10 kW motor	10,900	19,600
Rotary mixer	1	6 m^3/hr	11 kW motor	14,900	56,000
Bucket conveyor	1	6 m^3/hr		21,000	16,200
Blowers vents pipes	2	600 m^3/hr rotary pistons	15 kW	31,400	47,400
Bioreactor	1	.95 cm	8 m H x 6 m ID	67,400	261,700
Drag conveyor	1	4.5 m^3/hr	11 kW motor	33,700	27,800
Windrows		10.75 m^3/d	15 m L, 5 m W	14,200	1,000
General facilities		--	--	--	81,700
Installation Costs					
Gas measurement system				6,900	
Buildings				159,800	
Foundations				21,300	
Electrical				39,300	
Site preparation				40,000	
Startup costs				22,500	
INSTALLED COST				690,000	816,600

Note: D = diameter H = height ID = internal diameter L = length W = width

(a) These costs were obtained from the Hochheim City Engineer's Office.

The estimated cost of the general facilities is assumed to be equal to 10 percent of the total installed cost.

Assuming a contractor's fee of 11.1 percent and contingencies at 15 percent the estimated total plant investment of the Hochheim process is $1,043,300 (see Table 13). Licensing fees are based on the annual capacity of the plant and for this capacity (2.0 dry tonne per day or 500 tonne annually) the fees are $20,000 per year. The estimated total capital requirement is $1,225,800 (see Table 14).

Land cost is not included in the estimated total capital requirements (Table 14) due to the variability in land price with location. Land cost should not exceed 10 percent of the total plant investment.

Although the BAV process was established to reduce the time required for windrowing the compost, the land requirements for the Hochheim system are approximately the same as those for the aerated pile process. This is due to seasonal variations in the demand for the cured compost. The storage area at the Hochheim site has been developed to allow for periods of low-demand and, therefore, the land requirement is not significantly different than that which may be required for a windrow process without pretreatment (such as A.R.S.).

The estimated annual operating costs are $138,400 and the maintenance costs are $97,200. Assuming a dry solids throughput of 2.0 t/d and 250 operating days per year, the operating and maintenance costs are $471.20 per tonne (Tables 15 and 16) of solids per day or $428.36 per short tonne of solids per day. This estimate does not include the cost of transporting the sludge from the treatment plant to the composting site. In addition, no debit or credit has been taken for disposal of the sludge.

If the same method* of annualized cost estimation given in Reference 15 for aerated piles which includes site development, equipment, and land is used for the Hochheim process, the capitalized costs per year are $270,000 or $541.20 per dry tonne. The total annualized costs (capital + operating and maintenance) are therefore $1,012.40 per dry tonne. Almost one-half of this total (or $460 per dry tonne) can be attributed to the cost of dewatering sludge. This cost is unusually high compared to American experience. For example, dewatering costs for the aerated pile process are estimated to be $53.90 per tonne (16). Therefore, if the same cost for dewatering in the aerated pile process is applied to the Hochheim plant, the total cost would be $605.9 per dry tonne.

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*Annualized cost basis from Reference 15:

	% of Total Cost	Capital Recovery Factor
Site development	52.6	0.0736 (6.125%, 30 years)
Equipment	36.8	0.1367 (6.125%, 10 years)
Land	10.6	0.6125 (6.125%, infinity)
Total annualized cost	100.0	

TABLE 13. ESTIMATED TOTAL PLANT INVESTMENT OF BAV PROCESS AT HOCHHEIM FOR A 250 m^3 SLUDGE/DAY (2.0 dt/d) PLANT

	BCL Estimate, $
Total installed costs	816,600
Contractor's fee (11.1 %)	90,600
Subtotal	907,200
Contingency (15%)	136,100
Total Estimated Plant Investment (TPI)	1,043,300

TABLE 14. ESTIMATED TOTAL CAPITAL REQUIREMENT OF BAV PROCESS AT HOCHHEIM FOR A 250 m^3 SLUDGE/DAY (2.0 dt/d) PLANT

	BCL Estimate, $
Total plant investment (TPI)	1,043,000
Allowance for funds used during construction (TPI x 1 yr x 0.09)	93,900
Licensing fees (annual cost/yr)	20,000
Startup costs (20% of total gross annual O&M costs)	47,000
Working capital	
14-day inventory of raw materials:	
sawdust (12.5 m^3/d x 14 d x \$0.44/m^3)	100
coagulant (50 kg/d x 14 d x \$3.3/kg)	2,300
materials and supplies (0.9% of TPI)	9,400
net receivables (1/24 annual O&M costs)	9,800
Total Estimated Capital Requirement	1,225,800

TABLE 15. ESTIMATED ANNUAL OPERATING COSTS OF BAV PROCESS AT HOCHHEIM FOR A 250 m^3 SLUDGE/DAY (2.0 dt/d) PLANT

	BCL Estimate, $
Raw materials	
sawdust (12.5 m^3/d x 250 d x \$0.44/m^3)	1,400
coagulant (50 kg/d x 250 d x \$3.3/kg)	41,400
Purchased water (3000 m^3 x \$0.166/m^3)	500
Electricity (173,500 kWh x \$0.025/kWh)	4,300
Labor (1-1/2 men/shift x 2080 manhours/year x \$8/manhour)	25,000
Supervision (20% of labor)	5,000
Administration (60% labor + supervision)	18,000
Supplies (30% of labor)	7,500
Local taxes and insurance (2.7% of TPI)	28,200
Wastewater disposal (32,700 m^3 x \$0.2179/m^3)	7,100
Total Estimated Annual Operating Costs	138,400

TABLE 16. ESTIMATED ANNUAL MAINTENANCE COSTS OF BAV PROCESS AT HOCHHEIM FOR A 250 m^3 SLUDGE/DAY (2.0 dt/d) PLANT

	BCL Estimate, $
Maintenance labor (0.6 x 0.06 x TPI)	37,600
Supervision (20% of maintenance labor)	7,500
Administration (60% of labor + supervision)	27,100
Supplies (0.4 x 0.06 x TPI)	25,000
Total Estimated Annual Maintenance Costs	97,200

The annualized cost of the Hochheim process is compared with estimates of several other disposal methods in Table 17. These values are listed for purposes of illustration and can be considered "ball park" estimates only. They represent the best available estimates reported in the literature. To establish a rigorous method of comparison, estimates should be made of the other sludge disposal processes on the same basis as that used for the Hochheim process.

The estimates for landfilling, landspreading, trenching, and incineration are given as a range of values due to the cost variations reported in the literature for these disposal methods (15). Estimates of capital recovery, operating and maintenance costs have been included in the total. In addition, a charge of $53.90 per tonne has been added to account for dewatering costs (16). Based on figures reported in the literature (17), the annualized cost of sludge disposal by the aerated pile method has been estimated for a capacity of 9.1 dry tonne per day (the smallest capacity demonstrated). (The aerated pile method is operated 365 days per year.*) Transportation costs of the sludge to the disposal site have not been included.

The estimate of total annual cost of the Hochheim process is higher than the costs for landfilling, landspreading, trenching, and aerated piles. However, these comparisons must be viewed cautiously since several sources have been used to develop this information (15,16,17).

*The 365-days per year is based on the USDA Beltsville operation; realistically, and especially in northern climates, weather factors could significantly influence throughput. In these situations the unit cost for the USDA aerated-pile technology could be increased significantly. As an example, protective buildings for sludge storage may be required.

TABLE 17. COMPARISON OF TOTAL ANNUAL COSTS FOR SLUDGE DISPOSAL METHODS (1st Quarter 1978 U.S. Dollars)

Method[a]	Annual Processing Cost, $/t of Dry Solids	Annual Disposal Cost, $/t of Dry Solids
BAV process[b]		
Without dewatering cost	552	
With dewatering costs from Hochheim experience	1,012	
With dewatering costs from aerated piles, Beltsville, Md. plant experience	605.9	
Aerated piles[c]		
Without dewatering cost	126.4	
With dewatering cost from Beltsville, Md. plant	180.3	
Landfilling[d]		80.2 - 114.6
Landspreading[d]		83.7 - 163.8
Trenching[d]		186.7 - 207.3
Incineration[d]		119.2 - 160.4

(a) These operating costs cannot be used for direct comparison since different end-products are involved. The BAV and aerated pile methods produce a product for possible sales, whereas the others involve disposal; the cited cost is for processing, and no credit for sales has been included. There are also significant differences in land requirements for the different methods.

(b) Calculations are based on information obtained at the Hochheim facility. Care should be exercised when these values are compared with other sludge disposal options due to the differences in the scale of operation. The BAV method could have a reduced requirement for land compared to some of the others.

(c) Annual cost obtained from Reference 16 for 9.1/tonne per day capacity plant, updated to first quarter 1978; includes dewatering cost of $53.90 per tonne (16).

(d) Annual cost updated to first quarter 1978 (15); includes dewatering cost of $53.90 per tonne (16). No heat recovery is included in the incineration method.

SECTION 6

CONCLUSIONS

The conclusions of this report will be presented in two parts. Part I relates to the first objective of this study in which existing European sewage sludge composting practices were identified and available information gathered on their operating modes, effectiveness, reliability and costs.

Part II is related to detailed study performed at the Hochheim am Main composting plant. The purpose was to obtain experimental data to evaluate the effectiveness and reliability of the process as well as to assess process economics. Part IIB relates to the economics of the process at Hochheim.

Part I

1. The feasibility of composting sewage sludge mixed with a bulking agent is well established by European companies.

2. The future of general composting technology in Europe depends more on developing economic end-use markets and on continued public acceptance rather than technological process improvement.

3. In general, the quality of the compost produced from sludge/sawdust or tree bark is better than the quality of the compost produced from MSW/sludge. The better quality is due to the higher amount of degradable material that exists in sludge.

4. A condition for good composting of the sludge is that the water content of the mixture must be kept at a level of 50-55 percent. A major possible problem in sludge composting is the heavy metal content of the sludge, and this parameter should be controlled carefully. However, quantification of any effect which might exist is beyond the scope of this study.

Part II

The following conclusions are based upon the data obtained only at the Hochheim composting plant. These conclusions may or may not apply to other composting units using the same process. Further studies would be needed

before any definitive evaluation of the BAV system could be made. Recognizing that this is a very site-specific case, the conclusions regarding the Hochheim am Main plant during the period of the investigation are:

Part IIA

1. Effective use of the reactor volume available for stabilization was not achieved during the investigation. While it is impossible to establish a cause-effect relationship, the following factors are felt to influence the process operations:

   - The feedstock moisture content was probably too high.
   - The feedstock mixture ratio of sludge, sawdust and recycle was questionable.
   - The mechanical design did not anticipate relative deviation from optimal operating conditions.

Part IIB

1. The BAV process as operated at the Hochheim am Main Plant is a relatively capital-intensive process as compared to the USDA ARS aerated-pile system, but its labor requirement is lower.

2. An installation built in the U.S. would most likely have a higher investment than an equivalent European system due to the redesign or adaptation of European equipment to U.S. equipment specifications.

3. The BAV process may be amenable to only a limited economy of scale due to the probable restrictions on air distribution, product removal requirements, and compaction of solids at the base of the bioreactor.

4. The total annualized costs for the BAV process at Hochheim am Main are higher than those for aerated piles, landfilling, spreading, leveling, and incineration based on the best available data for comparison. These cost comparisons must be viewed very cautiously because it was not possible to develop all the estimates on the same basis within the time frame and cost scope of the study.

SECTION 7

RECOMMENDATIONS

Based upon the results of this study, the following recommendations are offered:

1. At least one other (or more) process configuration of a mechanical within vessel composting system should be evaluated in detail along with a similar evaluation of a second BAV process site. It may be desirable to evaluate a system which employs an externally-mounted product-removal mechanism and which mixes the composting mass during the active fermentation period. An example of this system is the Triga-designed St. Palais sewage sludge composting system at the Royan, France, wastewater treatment plant. Also, it may be desirable to evaluate the Weiss within vessel system, since a process claim indicates that the composted product extraction problem may have been solved. This study should occur over a longer time frame, to account for seasonal variations.

2. The Schnorr and Homogeneous Composting Stabilization (HKS) processes should be evaluated and compared to additional "within vessel" data.

3. The Swedish SNPD aerated-pile composting experiments in arctic climates should be compared to the USDA ARS system. The objective of the SNPD experiments is to determine the combined effects of cold intake air temperature with various types of contaminated sewage sludge on the composting rate.

4. The effect of heavy metals in sludge composting systems needs to be evaluated.

5. Economic evaluations of several different composting methods should be conducted by a single source to provide a uniform basis of comparison.

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APPENDIX A

LIST OF EUROPEAN MANUFACTURERS AND REPRESENTATIVES

The following is a list of (1) the European manufacturers and their European representatives of sewage sludge composting equipment and (2) government environmental protection officials, city administrators, and composting plant operators, who were contacted during the course of the program.

DANO
Via alle Dobbie, 2
CH - 6924 SORENGO/LUGANO

Mr. V. Stahlschmidt

Gebrüder Bühler AG
CH - 9240 UZWILL

Mr. H. Hofer and Mr. H. Weber

Industrie-Werke Karlsruhe Augsburg AG (IWKA)
Brikollare Process
Postfach 3409
D - 7500 KARLSRUHE 1

Mr. F. Beichel and Mr. H. Schriewer

TRIGA
33, avenue du Maréchal Joffre
F - 92000 NANTERRE

Mr. G. During, General Manager, and Mr. B. Parent

Carel Fouché Languepin
55, rue d'Amsterdam
F - 75008 PARIS

Mr. P. Giloux, Manager DRU Department, and Mr. Roumens

S.G.A.D.
B.P. 20
F - 13267 MARSEILLE Cedex 2

Mr. Ch. Richaud

P.L.M.
Fack
S - 20110 MALMÖ Sweden

Mr. B. Hansen, Vice President, General Manager Technical Activities

Ministère de l'Environnement et du Cadre de Vie
D.P.P.N. - S.P.D.S.
14, bld du Général Leclerc
F - 92521 NEUILLY sur Seine Cedex

Mr. B. Pommel and Mr. P. Godin

Agence Financière de Bassin "Seine-Normandie"
10-12 rue du Capitaine-Ménard
F - 75732 PARIS Cedex 15

Mr. J. Bazin, Inspecteur Général

Commission of the European Communities
Environment and Consumer Protection Service
Rue de la Loi, 200
B - 1049 BRUSSELS

Mr. L. Klein, Head of the Waste Management Division and Mrs. L. Pavan

Department of the Environment
2 Marsham St.
LONDON SW1P 3EB England

Mr. J.F.A. Thomas and Mr. Porteous

Water Research Center
Elder Stevenage
HERTFORDSHIRE SG1 1TH England

Dr. R. D. Davis and Dr. E. Cocker

Wanlip Composting Plant
Fillingate
Wanlip
LEICESTER England

Mr. Hughes, Plant Manager

The National Swedish Environment Protection Board
Technical Department
Fack
S - 17120 SOLNA Sweden

Mr. O. von Heidenstam, Deputy Head of Municipal Division

République et Canton de Genève
Département des travaux publics
Service Assainissement et contrôle des pollutions
Rue D. Dufour, 5
CH - 1205 GENEVE

Mr. P. Spoerli, Head of the service and Mr. Kroepfli

Biologische ABF allverwertungsgesellschaft MBH Co.
(BAV)
Berliner Strasse 22
D-6369 SCHOENECK 1

Mr. Nemetz, and Mr. S. Schmidt

Representative in U.S.A.:
Josef Meyer
175 East Short Road
Great Neck, New York 11023

APPENDIX B

SUMMARY OF A COMPOSTING STUDY CONDUCTED ON THE TRIGA SYSTEM BY THE DEVELOPER

RESEARCH ON THE INFLUENCE OF THE CHARACTERISTICS OF THE SLUDGE

In 1975, Triga conducted a study, with the financial support of the water agency "Seine Normandie", on the evaluation of the combined composting of MSW and sludge (18). This report must be viewed as somewhat favorable to the Triga system, since in this study plant operating conditions appear to be more controlled than was found at the BAV plant in Hochheim am Main. However, Battelle scientists have made on-site observations of the Triga process at St. Palais and Dreux, France. The study was performed at the Dreux plant. Based upon these on-site observations, and the results of the Triga study, Battelle recommends that further evaluation of the Triga process be undertaken.

Four types of raw sludge were tested:

- Tests No. 1 and 2: sludge from the town of Montargis flocculated with lime and $FeCl_3$ and dewatered by vacuum filtration. Water content: 75 percent;
- Test No. 3: sludge from the town of Chateauroux flocculated with a cationic polyelectrolyte "Fleurgey FC 250" and dewatered by centrifugation. Water content: 72 percent;
- Test No. 4: sludge from the town of Montargis taken from the primary and secondary settling tanks. Water content: 95 percent;
- Test No. 5: sludge from the town of Reims flocculated with lime and $FeCl_3$ and dewatered by pressure filter. Water content: 62 percent.

Raw sludge was preferred to digested sludge because its composting ability is better according to the fertilizer value shown in Table B-1.

TABLE B-1. N, P, K ANALYSIS OF SLUDGES AS A PERCENT OF THE DRY MATTER WEIGHT

	N %	P_2O_5 %	K_2O %	Organic Matter %
Raw sludge	3.5 to 4.5	2 to 3	0.5 to 1	60 to 80
Digested sludge	2 to 2.5	1 to 2	0.2 to 0.5	40 to 65

The procedure for these tests was as follows:

- The iron was removed from the MSW before the latter was ground,
- Sludge was then added to the MSW in order to get a mixture with a 50 percent water content.

Table B-2 gives the composition of the different mixtures. Table B-3 gives an analysis of the MSW and the sludges used for the tests.

The mixture was then fed into the tower called "Triga Hygienisator". During the tests, the following parameters were controller:

- temperature,
- moisture,
- air flow rate,
- O_2 and CO_2 concentration of the off-gases.

Mixing of the Sludge and the MSW

The mixing of the sludge and the MSW is directly linked with the water content of the sludge. There was no problem for Tests 1 to 4. There were some difficulties in Test No. 5. The sludge makes small flakes (1 to 3 cm) which do not mix very well with the MSW. To ensure good mixing, the sludge and the MSW were passed 3 times through a screw mixer (6 m long).

Within-Vessel Composting

The purpose of within-vessel composting is to reach a temperature of 70°C as quickly as possible. This temperature is reached after 4 days for the MSW alone. For the mixture (sludge and MSW) the time depends on the composition of the mixture and the type of sludge.

Tests No. 1 and 2: digestion was carried out without difficulties in 2 days.

TABLE B-2. COMPOSITION OF THE MIXTURES

Test no		1	2	3	4	5
Municipal Solid Wastes (MSW)						
Weight	tonnes	35	61	21,5	63,4	21,6
Water content	%	35	33	36	39	40
Sludge						
Weight	tonnes	25	35	17,4	(16 m^3)	18,3
Water content	%	75	75	72	95	62
Mixture						
Water content	%	52	48	49,8	50	49,1
Sludge/MSW ratio (dry basis)	%	21	16	27	2	36

TABLE B-3. CHARACTERISTICS OF THE MSW AND SLUDGES (Analysis: C.D.L.P. Melun)

		Municipal Solid wastes	Sludge tests 1 & 2	Sludge test 3	Sludge test 4	Sludge test 5
pH		5.9	12.4	6.8	5.85	14
C/N ratio		31.9	11.2	15.3	10.4	12.3
Water content	%	38	75	72	95.5	61.5
Chemical analysis (dry basis-% by weight)						
Organic matter	%	64.5	38.6	63.8	57.2	
Carbon	%	30.2	22.7	38.4	36.6	12.6
Nitrogen	%	0.9	2	2.5	3.5	1
P_2O_5	%	0.4		3	5.8	1.3
K_2O	%	0.2		0.17		0.09
CaO	%	2.9	25.5	5.4	9.7	33.7

Test No. 3: the mixture stayed 10 days in the tower, and the temperature did not rise above 55°C. The high concentration of heavy metals such as lead, boron and chromium could be responsible for the inhibition of the development of the microorganisms.

Test No. 4: the water content of the mixture was too high, and the temperature rose too slowly.

Test No. 5: the mixture was not homogeneous and the transfer of the sludge water to the MSW was poor. In order to adjust the moisture content of the mixture to 50 percent, a large amount of sludge was necessary. Thirty-six percent of the dry matter came from the sludge. The result was a mixture with a high density; therefore, the forced aeration was difficult.

Curing

At the exit of the tower the mixture was screened to a size of 25 mm. The curing period was 3 months for mixture No. 1 and 4 months for the others. During the first month, the mixtures were turned frequently and water was added to keep the water content at a level of 45-50 percent. Figures B-1 to B-4 give the evolution of the main parameters (temperature, water content, organic matter, C/N ratio) vs. the time.

CONCLUSIONS OF THE STUDY

Two conditions must be fulfilled to have good aerobic digestion; the water content of the mixture must be kept at a level of 50-55 percent, and the contribution of the dry matter of the sludge to the total dry matter of the mixture should be less than 25 percent.

Sludge with a water content under 70 percent is difficult to mix with the ground MSW.

A high concentration of heavy metals in the sludge could inhibit the development of the microorganisms.

After 4 months of curing, the water content, C/N ratio, organic matter content and pH are more or less the same for the 5 mixtures. Their values are independent of the type of sludge, and the C/N ratio of 15 is such that the humus can be applied to the soil without problem (Table B-4).

Sludge flocculated with polymeric organic chemicals is better than sludge flocculated with ferric chloride and lime.

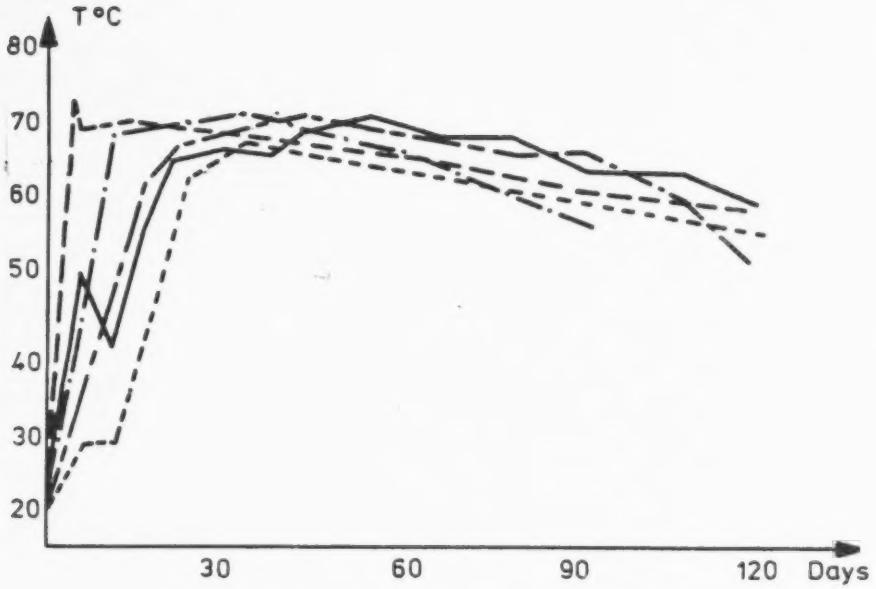
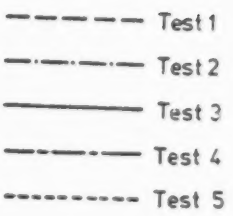


Figure B-1. Temperature evolution.



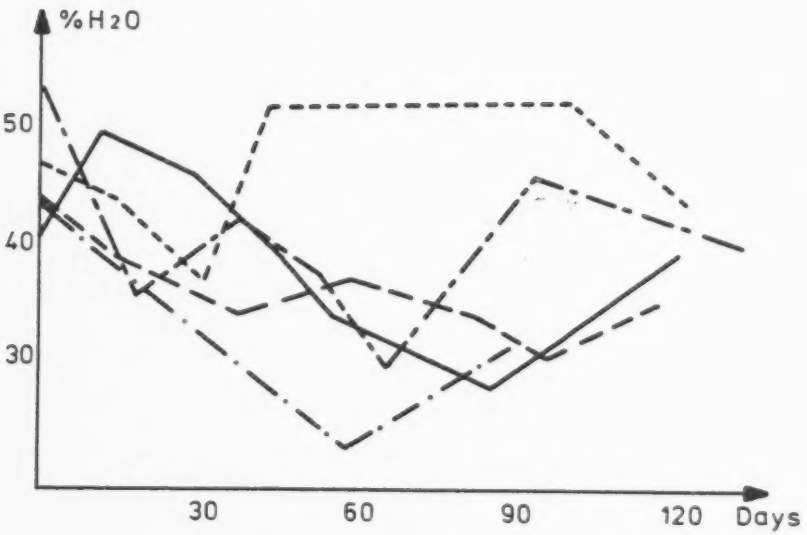


Figure B-2. Water content.

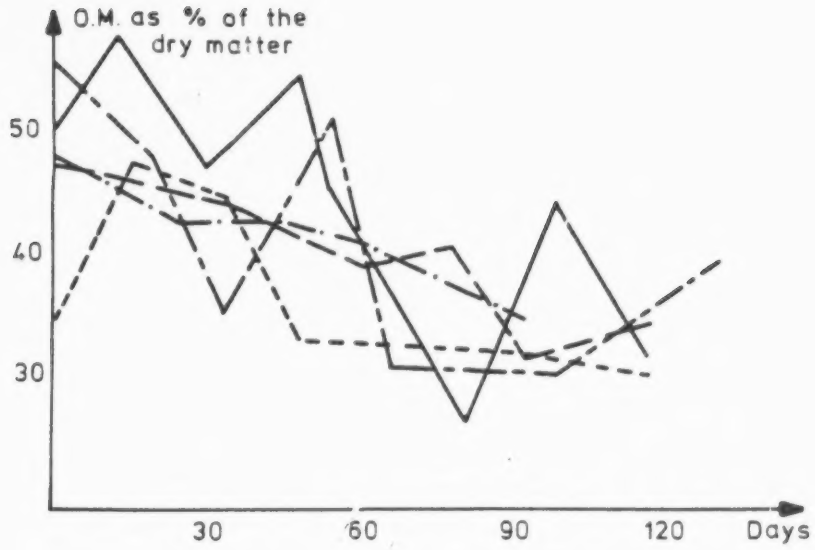
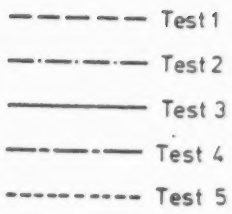


Figure B-3. Organic matter evolution.



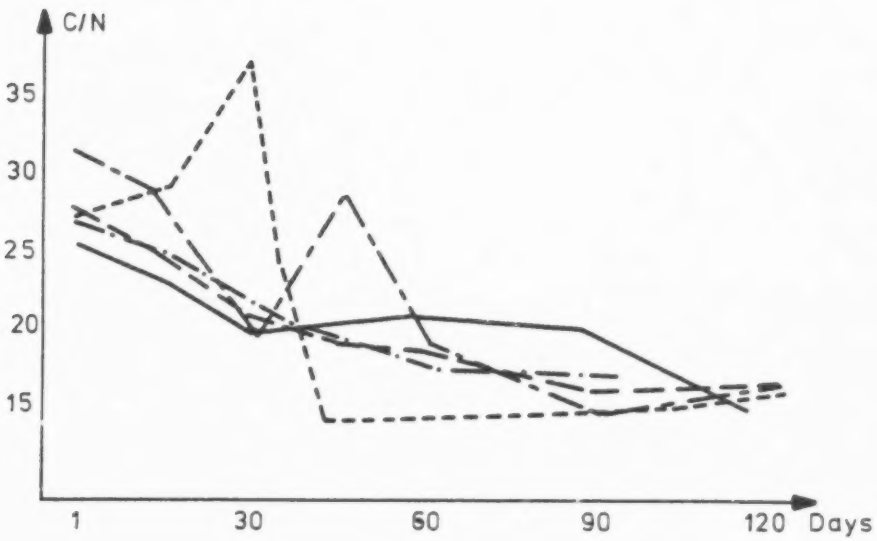


Figure B-4. C/N ratio evolution.

TABLE B-4. CHARACTERISTICS OF THE MIXTURE (Analysis: C.D.L.P. Melun)

Test		Before curing					After curing (4 months)				
		1	2	3	4	5	1	2	3	4	5
pH		6.8	7.8	6.6	5.7	7.9	7.9	7.9	8	7.9	7.5
C/N ratio		28.3	28.1	25.3	31.5	27	15.4	15.9	15	16.9	16
Water content	%	45	43.7	40.5	54.2	47	35.7	32	39.5	40	44
Chemical analysis (dry basis-% by weight)											
Organic Matter	%	47.7	47	40.5	56.2	34	34.4	35	32.2	38.2	30.3
Carbon	%	23.1	23	24.8	28.7	22	14.6	14.3	14.6	16.9	16.5
Nitrogen	%	0.8	0.8	1	0.9	0.8	0.9	0.9	1	1	1
P_2O_5	%	0.9			0.8	1.1	1.1			0.6	0.7
K_2O	%	0.3			0.1	0.3	0.4			0.3	0.3
CaO	%	8.9			3.7	4.3	11.2			4.4	9

APPENDIX C

THE HOCHHEIM TREATMENT PLANT COMPONENTS OPERATIONAL DATA

The sewage treatment plant in Hochheim am Main comprises the following components (see Figure C-1):

- roofed screening plant
- grit channel
- Venturi tube flow meter
- storm water tank
- preliminary clarification tank (volume: about 500 m^3)
- activated sludge tank (volume: about 1000 m^3; with fine bubble aeration
- secondary sedimentation tank (volume: about 3200 m^3; overflow to the receiving water course in the center)

These three components form one unit in a circular tank. The secondary sedimentation tank is in the middle, the preliminary clarification and the activated sludge tank are arranged around it.

- sludge thickener (volume: 417 m^3)

Analytical data from the laboratory records:

- Volume of sewage (mean value); about 5000 m^3/d (1.32 MGD)
- Five days biochemical oxygen demand:
  influent: 130-200 mg/ℓ
  effluent: 13-18 mg/ℓ
- Settleable solids:
  influent (preliminary clarification; after 2 hr): 0.2-1.7 mg/ℓ
  effluent (secondary sedimentation; after 2 hr): 0 mg/ℓ
- pH value: 6.6 - 7.6
- Transparency (secondary sedimentation tank): 50-70 cm.

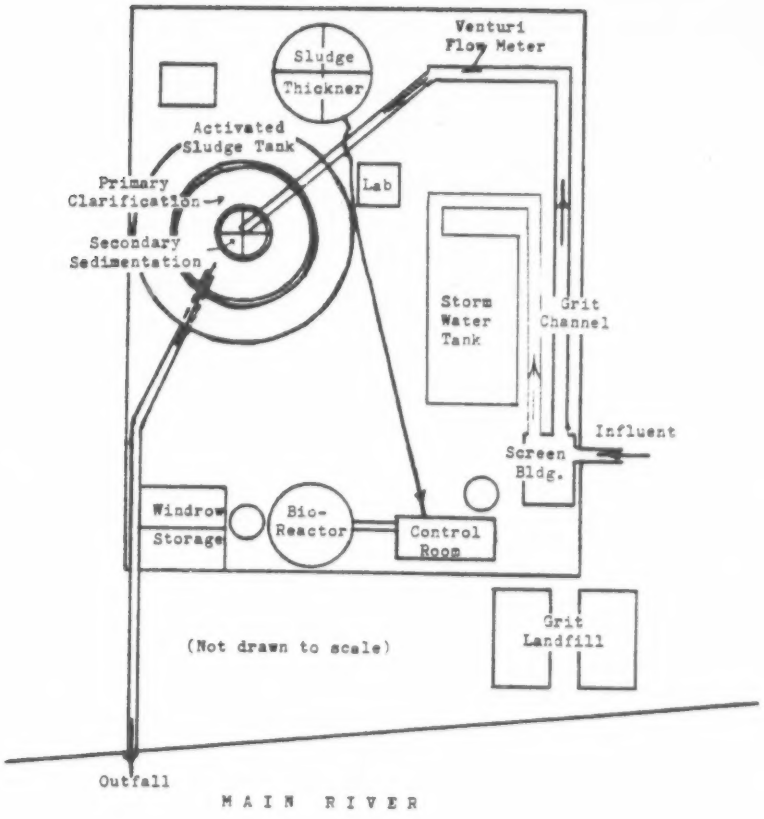


Figure C-1. Hochheim am Main, West Germany wastewater treatment plant layout.

APPENDIX D

ANALYTICAL METHODS USED IN THE EVALUATION OF THE TREATMENT PLANT IN HOCHHEIM, GERMANY

SAMPLE COLLECTION AND LOCATION

Bioreactor feedstock and final product samples were collected simultaneously during the two-hour filling and emptying period. The feedstock sample was collected at the point of entry, at the top of the reactor, while the bioreactor product was collected off of the product discharge conveyor belt. During the two-hour filling and emptying period, an aliquot of material was collected at 30-minute intervals. These five aliquots were composited into one sample, then thoroughly mixed, and from this composite approximately one liter of material was reserved for the following laboratory analyses:

Determination of the Loss in Drying at 75°C

The compost was weighed in large beakers and dried in the drying chamber at 75°C until it reached a constant weight.

Homogenization of the Compost

The dried samples (75°C) were broken up and homogenized in a laboratory-sized hammermill.

Determination of the Loss in Drying at 105°C

The compost which had been dried at 75°C and homogenized was dried at 105°C.

Determination of Ash Content at 600°C

The compost sample which had been homogenized and predried at 75°C was weighed into a porcelain crucible and reduced to ashes by heating in a muffle furnace at 600°C until a constant weight was achieved.

Determination of Ash Content at 900°C

The same ash which was determined at 600°C was further heated in a muffle furnace at 900°C until a constant weight was achieved.

Determination of C and H Content

The compost sample which had been dried at 105°C was burned by means of semimicro-elementary analysis in a Heraeus combustion furnace and the H_2O or CO_2 resulting from combustion was gravimetrically determined.

Determination of N Content
According to Dumas

The sample dried at 105°C was burned in a Heraeus combustion furnace using CO_2 as a carrier gas and the resulting nitrogen was determined using gas volumetric methods.

Determination of O Content
According to Unterzaucher

The sample, dried at 105°C, was decomposed in a Heraeous combustion furnace using N_2 as a carrier gas and the gases resulting from decomposition were passed over coal heated at 1120°C. The resulting carbon monoxide was idometrically determined following its reaction with iodine pentoxide.

Determination of S Content

The sulfur content was determined by burning the sample dried at 105°C in an oxygen current, whereby the resulting sulfur dioxide was oxidized in an absorption vessel containing H_2O_2 to form sulfuric acid which was then conductimetrically analyzed.

Determination of the Calorific
or Lower Heat Values

The calorific value was determined using the sample dried at 105°C in a bomb calorimeter. The water resulting from combustion was taken into account in the calculation.

Analytical data are reported in Table D-1.

TABLE D-1. CHEMICAL AND PHYSICAL DATA OBTAINED AT THE HOCHHEIM AM MAIN, WEST GERMANY BIOREACTOR, APRIL 12 to JUNE 2, 1978

Date	Sample	% Weight Loss		% Ashes		% C*)	% H*)	% N*)	% O*)	% S*)	Lower Heat Value kJ/kg
		75 °C	105 °C	600 °C	900 °C						
04/12/78	entry	67.3	68.7	8.37	8.25	45.8	5.65	1.88	35.9	0.31	17224
04/12/78	exit	64.1	65.4	9.27	9.12	44.8	5.60	1.48	34.9	0.41	16396
04/13/78	entry	65.9	67.2	5.98	5.93	46.7	5.73	1.26	38.0	0.23	16473
04/13/78	exit	66.2	67.4	7.88	7.76	45.8	5.64	1.36	36.8	0.29	17296
04/14/78	exit	58.9	65.3	8.52	8.46	44.6	5.52	1.41	37.5	0.27	16584
04/17/78	entry	64.3	66.0	6.43	6.39	46.5	5.73	1.65	34.8	0.20	17430
04/17/78	exit	61.9	63.6	9.79	9.68	44.3	5.40	1.45	36.1	0.30	16534
04/18/78	exit	57.3	63.0	8.26	8.18	44.3	5.35	1.62	36.2	0.27	16613
05/29/78	exit	50.7	52.8	7.86	7.81	44.7	5.48	1.54	37.3	0.27	16990
05/30/78	entry	64.8	66.7	10.51	10.27	45.8	5.59	1.45	36.6	0.21	16509
05/30/78	exit	58.0	59.5	9.83	9.73	44.7	5.55	1.53	37.5	0.24	16375
05/31/78	entry	65.2	67.0	8.05	7.87	45.1	5.66	1.54	36.2	0.20	16977
05/31/78	exit	54.3	56.1	9.68	9.57	45.8	5.51	1.58	36.2	0.24	16483
06/01/78	entry	66.4	66.4	10.31	10.26	45.5	5.62	1.19	35.8	0.22	16663
06/01/78	exit	56.3	58.0	11.09	10.75	42.6	5.06	1.66	34.9	0.23	16636
06/02/78	entry	64.5	66.1	7.65	7.31	47.0	5.74	0.86	38.0	0.16	17472
06/02/78	exit	51.5	52.9	12.44	11.83	44.4	5.44	1.55	36.0	0.25	16806
relative error		± 1%	± 1%	±1%	±1%	± 0,5%	± 1%	± 5%	± 1%	± 10%	± 2%
Average	entry (7)	65.0 (1.1)	66.8 (0.9)	8.97 (2.0)	8.04 (1.7)	46.1 (0.7)	5.67 (0.06)	1.4 (0.33)	36.5 (1.18)	0.22 (.05)	16946
	exit (10)	57.9 (5.8)	60.4 (5.3)	9.46 (1.5)	9.29 (1.3)	44.6 (0.9)	5.46 (0.16)	1.5 (0.09)	36.3 (0.95)	0.28 (.05)	16671

*) Average value from double determination

APPENDIX E

ORGANOLEPTIC ODOR EVALUATION

The composting plant comprises the following characteristic odor sources:

- activated sludge tank
- bioreactor
- windrows (secondary fermentation).

Organoleptic studies use the human nose as detector and analyzer and sensory perception is the criterion for evaluation.

KIEL TO-4 OLFACTOMETER

In the present study the odor qualities were described and the thresholds of typical odor profiles determined olfactometrically, using dilution methods. In addition to the known scentometer I-3 (Barnebey Cheney, Columbus, Ohio), the Kiel Olfactometer TO-4 was used for this. The latter operates on pure air or oxygen from commercial steel cylinders, and is used for mixing a constant synthetic air stream with a controllable stream of ambient air (cf. block diagram, Figure E-1).

The pure air from the cylinder is passed through a pressure reducing valve in an absolutely odor free tube and is used for operating a gas jet pump. Via an adjustable throttle valve and flow meter this gas jet pump draws in odorous ambient air and mixes it intensively with the odorless synthetic air. The mixture flows through a tube to the breathing mask. The mixing ratio of synthetic air or oxygen to ambient air at the odor threshold is used as measure of odor intensity.

Care was taken that the olfactory cells could recover between measurements.

The scentometer, Model I-3, operates on the same principle as the Kiel olfactometer, Model TO-4, except that the dilution air used is ambient air which has been purified by passing the ambient air through a bed of activated charcoal. The activated charcoal bed is an integral part, and is located inside of the scentometer.

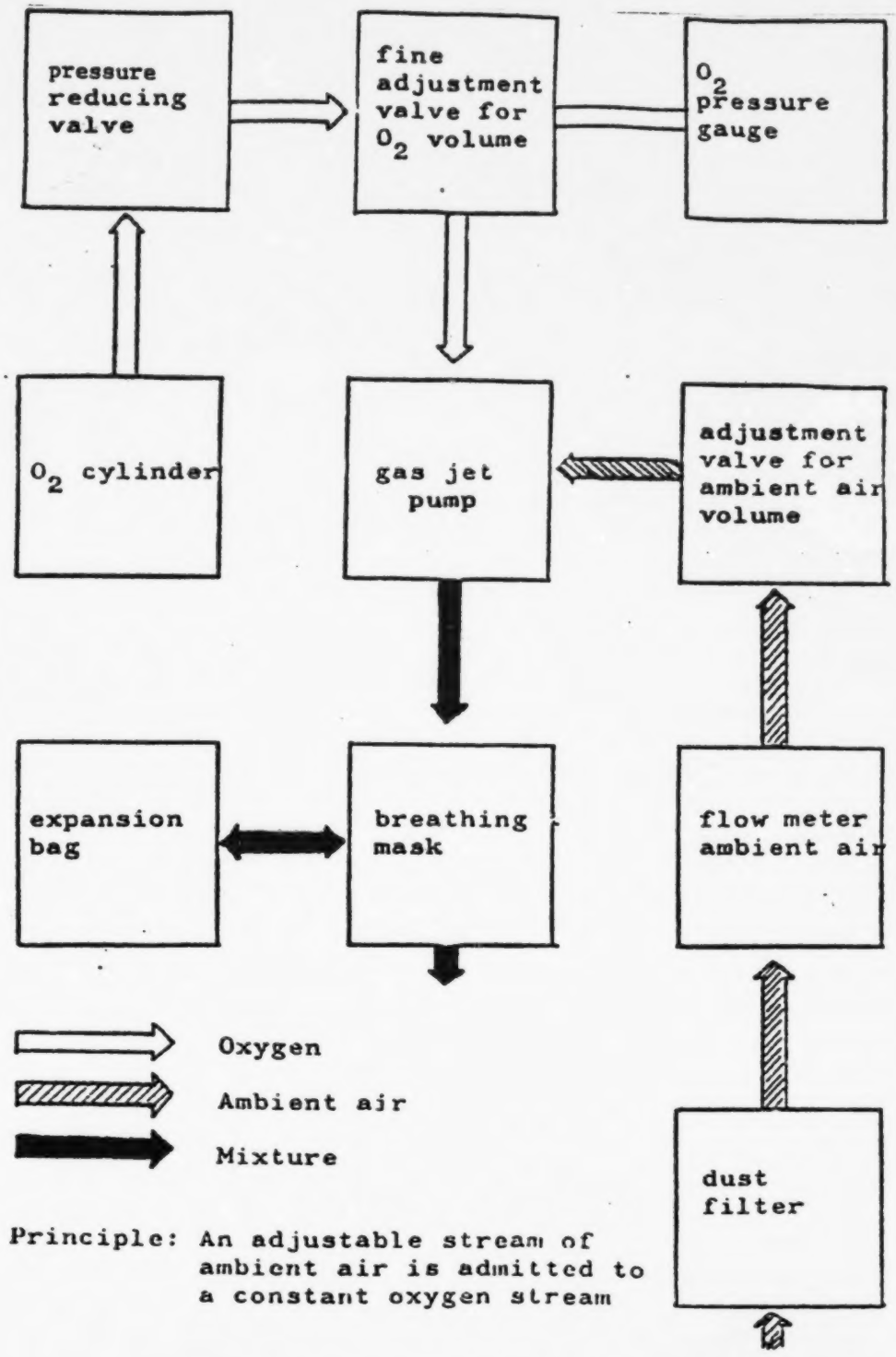


Figure E-1. Block diagram of the portable Kiel olfactometer TO-4.

ACTIVATED SLUDGE TANK

Characterization of the Odor Profile

Sensation: unpleasant

Odor characterization	Intensity or order of perception
• brackish-sweetish	+++
• fecal	++
• rotten	+
• sewers	
• cabbage	
• rakings	
• suds	

Odor Intensity (Olfactometric Evaluation of Odor Emission)

(a) I-3 (DT = dilutions to threshold): 1:350

(b) TO-4 (volumetric ratio of odorous to pure air): 1:33

BIOREACTOR (EMPTYING)

Characterization of the Odor Profile

Sensation: unpleasant

Odor characterization	Intensity of order of perception
• liquid manure, sweetish-sour	+++
• ammonia	++
• peaty	+
• earthy	
• fermentation (silage)	

Odor Intensity (Olfactometric Evaluation of Odor Emission)

(a) I-3 (DT = dilutions to threshold): 350

(b) TO-4 (volume ratio of odorous to pure air): 1:200

WINDROWS

Characterization of the Odor Profile

Sensation: unpleasant

Odor characterization	Intensity of odor of perception
• ammonia, sourish	+++
• fermentation, dung	++
• slightly earthy	+
• henhouse	+
• spoiled (degraded) potato	

Odor Intensity (Olfactometric Evaluation of Odor Emission)

(a) I-3 (DT = dilution to threshold): 350

(b) TO-4 (volumetric ratio of odorous to pure air): 1:50

Whereas the scentometer did not permit any differentiation between the three odor sources to be made, marked differences in the emission from the three sources were identified with the TO-4 olfactometer.

SURROUNDING NEIGHBORHOOD AREA

Characterization of the Odor Profile

Odor concentration in the vicinity of the Hochheim plant depends on topographic and weather conditions, especially on wind direction and speed and on turbulence. If we consider the three odor sources or odor profiles, it is usually the odor from the bioreactor or a mixture from bioreactor and windrow odor which predominates, whereas the smell from the activated sludge tank is practically not perceived outside the plant area. As a result of topographical and orographical factors, odor concentration zones or islets may form whose characteristic odor profiles may be temporarily perceived in an area of several hundred meters.

Odor Intensity (Olfactometric Evaluation of Odor Concentration)

In the immediate vicinity of the plant area the scentometer sometimes, i.e., in the event of single gusts, recorded especially the odor from the bioreactor at DT quotients between 350 and 31.

On the hillsides to the North odor concentration zones formed from time to time between the buildings, depending on the prevailing air currents.

Except in the event of inversion conditions, however, the odor was generally carried off by relatively vertical currents of air.

Because of the specific and highly variable local conditions, it is impossible to record the different odor intensities in a general and reproducible planimetric form and represent them cartographically.

To be able to make generally valid statements about odor concentration in the vicinity of sewage treatment plants, the distribution of the odorous substances involved must be calculated. Depending on the quality and quantity of data available, this can be done with the aid of a conventional Gaussian distribution model or, using a more sophisticated and more universal numerical diffusion model.

The relatively simple Gaussian model uses the following equation for computing the concentration of odorous substances:

$$C(x,y,z) = \frac{Q}{2\pi\,\bar{u}\,\sigma_y(s)\sigma_z(x)} \exp\ -\frac{y^2}{\sigma_y^{\,2}(x)}\ \exp\ \frac{-z^2}{\sigma_x^{\,2}(x)}$$

where

C	concentration of odorous substance [mg/m^3]
x,y,z	coordinates between odor source and recording point
Q	strength of odor source mg/σ
$\bar{u}$	mean wind velocity
$\sigma_y(x)$, $\sigma_z(x)$	variation of concentration distribution in y and z direction

To be able to calculate the odor concentration C(x,y,z) the parameters $\sigma_y(x)$ and $\sigma_z(x)$ must be known in addition to the mean wind speed. These parameters can be described by the following equations (Klug: Staub 29, 143 (1969):

$$\sigma_y(x) = Fx^f \quad ; \quad \sigma_z(x) = Gx^g\,.$$

The parameters F, f and g depend on the atmospheric stability, the determination of which is described in detail in the quoted literature.

As the equation shows, the quantity of odorous substances emitted per unit time must be known, in addition to the meteorological parameters.

The following assumptions were made for assessing the odor concentration mathematically on the basis of the emission from the bioreactor:

1. Let the odor intensity of 1:200 (volumetric ratio of odorous to pure air), which was measured at one point

of the bioreactor be representative of the odor intensity within the entire bioreactor (homogeneous distribution).

2. Let the air flow be constant at 600 m^3/hr.

Based on these two assumptions the odor concentration in the main direction of distribution (i.e., as a function of the distance from the odor source) was calculated for two different meteorological situations.

The results of these calculations are shown in Figure E-2. Odor concentration is plotted as multiples of the odor threshold in this diagram. It is noted that even under the most unfavorable distribution conditions (Case I) the maximum value of odor concentration is as low as one-fifteenth of the threshold value. At higher wind speeds and atmospheric layers of low stability the maximum decreases in absolute terms and is located closer to the odor source (Case II). These calculations do not consider the influence of local topographical and orographical factors so that the experimentally determined odor concentrations zones or islets cannot be identified with the simulation model.

If the first of the two assumptions made is incorrect, detailed measurements are required in order to determine the source strength per unit time.

Therefore, it is suggested to determine the emission strength of individual key substances over an extended period of time (several days) by measuring the gradient of the threshold value and correlate the throughput of the bioreactor with the volume of odorous substance released. After having thus determined the source strength by measuring the flow rate of various odorous components, the distribution of the substance can be calculated with the above equation or, if detailed meteorological data are available, with a three-dimensional turbulent diffusion model.

A three-dimensional model of this kind (TRANSLOC) has been developed at Battelle-Institut e.V., Frankfurt am Main. This model features the special advantage that it can be used in the case of transient flow processes and under weak-wind and inversion conditions.

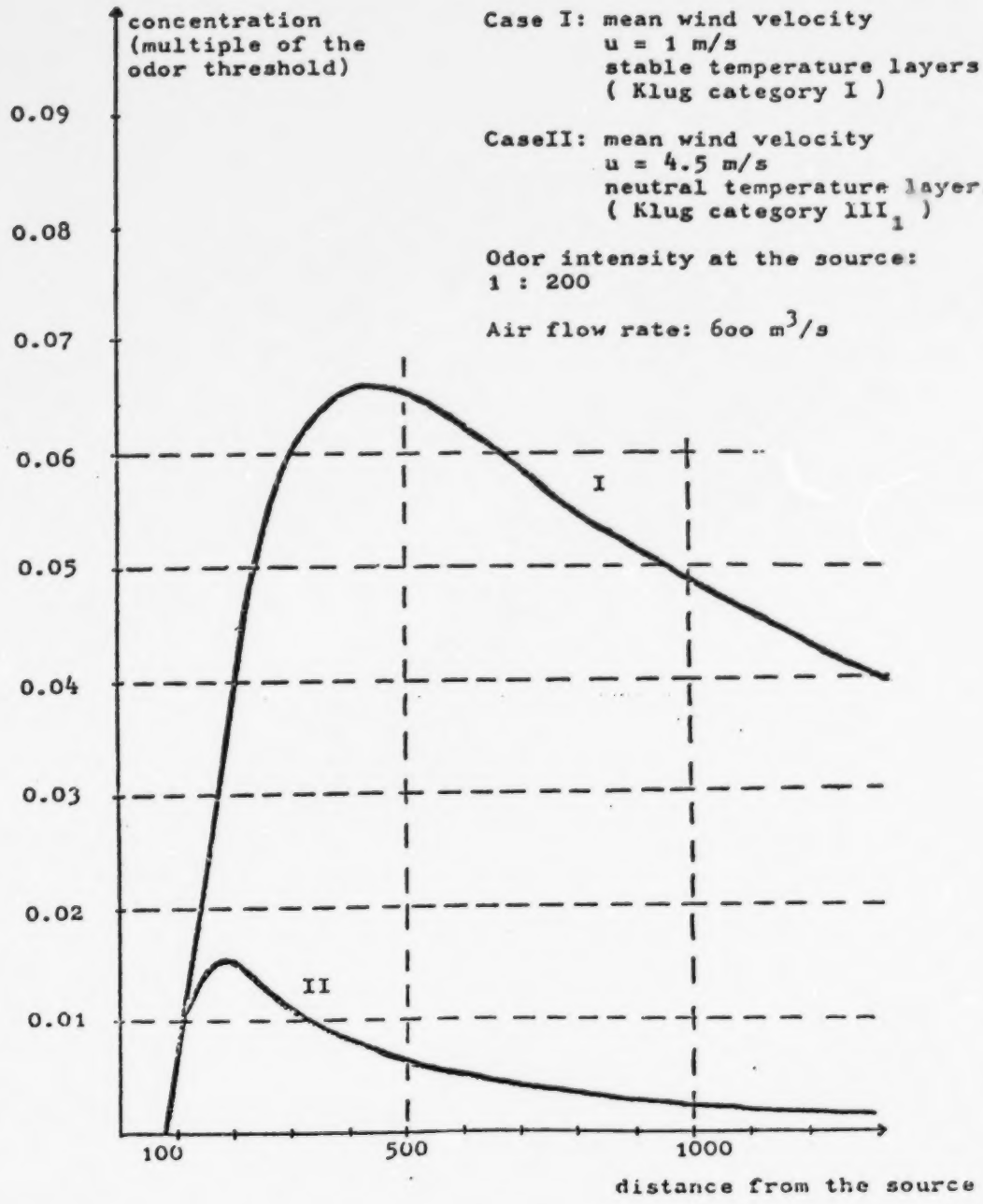


Figure E-2. Concentration of odorous substance in the main direction of distribution.

APPENDIX F

INFORMATION FOR COST EVALUATION SUPPLIED
BY HOCHHEIM PLANT PERSONNEL

The investment expenditures indicated below were taken from those bids received by the Hochheim town administration in response to bid invitations that were finally accepted.

The amounts have in part been estimated as the share of the composting plant in the price quote for the entire plant (including the sewage water treatment plant).

CAPITAL INVESTMENT ITEMS

Sludge Treatment and Composting Equipment

	No.	Price per unit (DM)	Total cost (DM)
1. Pumps for conveying sludge to sludge thickener	3	9,100	27,300
2. Sludge thickener (only cost of converting an existing digestion chamber)	1	35,500	35,500
3. a) Pump for feeding sludge to centrifuges	1	6,600	6,600
b) Pipeline from sludge thickener to centrifuges	-	--	24,900
4. a) Coagulant container (see Other Installed Costs)	2	--	--
b) Stirring devices	2	4,500	9,000
c) Proportioning pumps	2	5,550	11,100
d) Pipeline to centrifuges	-	--	10,800
5. Decanter centrifuges	2	88,350	176,700
6. Drag conveyor	1	53,500	53,500
7. Sawdust bunker (see Other Installed Costs)	1	--	--

		No.	Price per unit (DM)	Total cost (DM)
8.	Mill chain, delivered instead of the planned belt conveyor ordered at the same cost	1	9,600	9,600
9.	Thick-sludge bunker (see Other Installed Costs)	1	--	--
10.	Screw conveyor	1	21,800	21,800
11.	Return bunker (see Other Installed Costs)	1	--	--
12.	Screw conveyor	1	21,800	21.800
13.	Rotary mixer	1	29,700	29,700
14.	Drag conveyor	1	42,000	42,000
15.	a) Rotary piston blowers	2	25,400	50,800
	b) Ventilation pipes	-	--	11,900
16.	a) Bioreactor	1	120,000	120,000
	b) Temperature measurement system	1	7,800	7,800
	c) Level indicator	1	6,900	6,900
17.	Mill chain	1	67,300	67,300
18.	Windrows (see Other Installed Costs)	-	--	--
	Total			745,000
	Planned but not installed: gas measurement system (16 d)			(13,700)

Other Installed Costs

Building for decanter centrifuges, including coagulant container and foundations, and thick-sludge bunker and return bunker	319,500
Foundations for bioreactor	22,000
Attendant cabin	20,500
Sawdust bunker	26,000
Excavation work	62,000
Electrical switchboard plant	33,500

Other electrical installations (about 25% of the electrical installation costs of the entire plant, including sewage water	45,000
Stone paving especially for windrows, 350 m^2 (DM 81,000 per m^2 including substructure)	28,350
Bituminous surfacing	18,000
Ancillary services (transport insurance for materials, lodging for the workers during construction, training of the operating personnel, initial operating materials, start-up of the composting plant, warranty services for the one-year period, planning and contractor's fee)	45,000
Total	619,850

There were additional costs which are not generally incurred for other composting plants, especially for pulling down the existing sludge drying equipment and the non-usable conveyor apparatus, and for special excavation work which, however, was mainly for the sewage treatment plant.

Land Development Required

- Electric power supply about 80 kW
- Water supply
- Canal (if the plant is not located on the same plot of land as the wastewater treatment plant)
- Telephone line installation
- Road construction

Land Requirements

• Technical equipment (buildings, foundations, etc.)	250 m^2
• Windrows (height of stored material: 1,5 m)	300 m^2
• Sawdust bunker, area for transportation, etc.	400 m^2
	950 m^2

Licensing Fee

The licensing fee, which is paid when the plant comes into operation, is calculated as followes:

DM 20 per 1 kg solids content of the digested sludge per day.

At its present throughput (about 50 percent of the planned throughput), this would mean for the composting plant at Hochheim:

Volume of digested sludge: 125 m^3 day

Specific weight: about 1,000 kg/m^3

Solids content: 0.8 percent by weight.

Licensing fees:

$$125\ (m^3/d) \times 1{,}000\ (kg/m^3) \times \frac{0.8}{100} \times 20\ (DM/kg/d) = DM\ 20{,}000.$$

At full capacity, the licensing fees of the plant thus would amount to DM 40,000.

OPERATING COST ITEMS

Labor Requirements (Excluding Maintenance Staff)

One foreman full-time, with experience in wastewater and sludge treatment (40 hours per week), and one assistant worker, half-time (20 hours per week) are required.

The tasks of these persons include some repairs, lubrication, changing of oil, cleaning of the rotary mixer, etc.

Materials Required

Expensive spare parts are not included. The main materials required are:

- Sawdust: 6.25 m^3/d, 230-250 days per year; that is about 1,440-1,650 m^3 per year
- Coagulant: 50 kg/d, 230-250 days per year; that is about 11,500-12,500 kg per year (in Germany the price is about DM 2.80-3.40 per kg)
- Oil, grease: about DM 500 per year
- Not specially mentioned spare parts: about DM 500 per year.

Utility Requirements

- Electricity:
  - drive motors: about 50 kW, 4 hours per day, 230-250 days per year, that is 46,000-50,000 kWh per year
  - rotary blowers: one of the two blowers (each 15 kW) runs for 22 hours on 5 days a week, and 24 hours on the other two days; that means about 123,500 kWh per year
- Water: good quality, to dilute coagulant: 12 m^3/d, 230-250 days per year, that is 2,760-3,000 m^3 per year .

Waste Disposal Requirements

Wastewater from

• sludge thickener	85.0 m^3/d
• decanter centrifuge	45.8 m^3/d
Total	130.8 m^3/d

230-250 days per year: 30,084-32,700 m^3 per year .

MAINTENANCE COST ITEMS

Maintenance Requirements

The most expensive work, which can not be done by the workers of the plant, includes the following:

1. Discharge mill chain of bioreactor (No. 1 in Figure F-1); exchange of chain: once a year.
2. Drag-chain conveyor for the mixed input material of the bioreactor (No. 14 in Figure F-1); exchange of chain; every 3 years.
3. Additional different maintenance work of the electric equipment, several times a year at irregular intervals.

Labor Requirements

1. Discharge mill chain (No. 17 in Figure F-1); 2 workers with special experience are required for 3 days, i.e., 6 man-days per year.
2. Drag-chain conveyor (No. 14 in Figure F-1); 4 workers with special experience are required for 3 days, i.e., 12 man-days for one exchange, or 4 man-days per year.

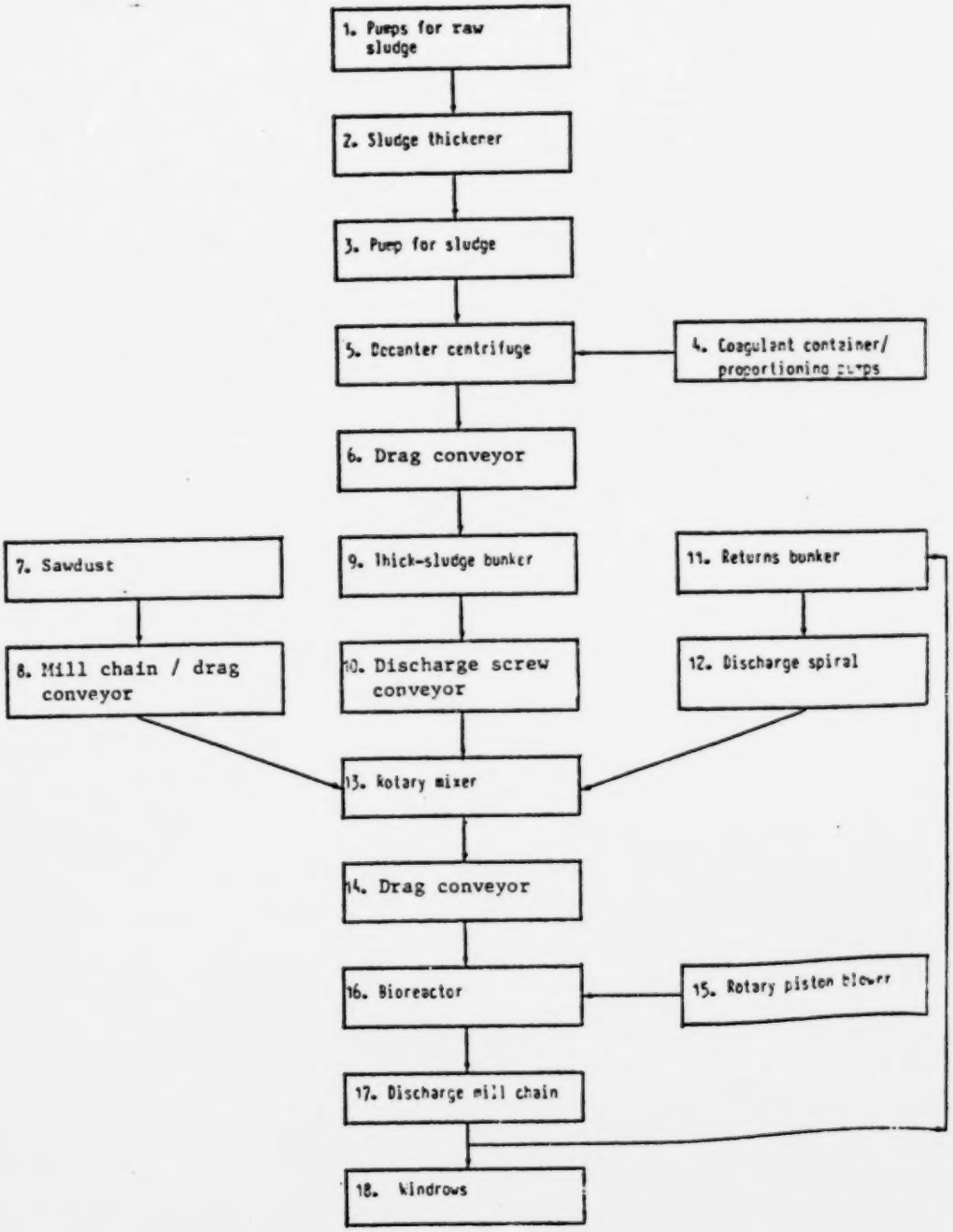


Figure F-1. System of components.

3. Electric equipment: 5 man-days per year of electrical work are required.

Materials Requirements

1.	Discharge mill chain (No. 17 in Figure F-1)	1,000 DM/year
2.	Drag-chain conveyor (No. 14 in Figure F-1);): The price of one chain is about DM 10,000, that is	3,333 DM/year
3.	Different materials (work to be done by the staff of the plant):	
	• Hydraulic system	
	- hoses: service life 2 years; 5 hoses per year, price of one hose: DM 128, that is	(640 DM/year)
	- solenoid valves: about	(360 DM/year)
	Total	1,000 DM/year
4.	Parts for high intensity mixer (No. 13 in in Figure F-1) (repaired very often):	4,000 DM/year
5.	Other spare parts: about	3,000-5,000 DM/year